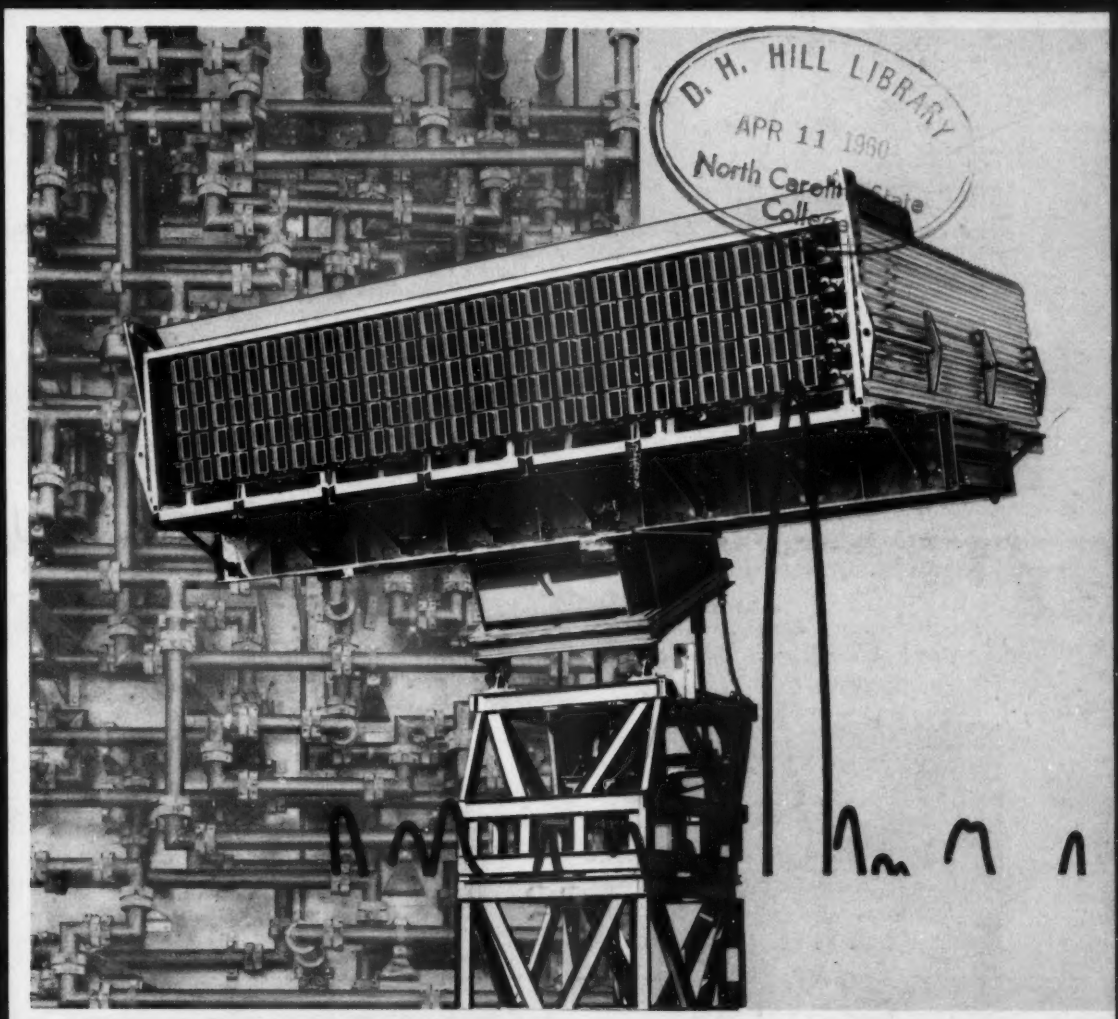
RAYTHEON

ELECTRONIC PROGRESS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A CORPORATE STRUCTURE ANTENNA

In this issue:

ELECTRONIC PROGRESS

Volume IV March-April 1960 Number 5

RAYTHEON

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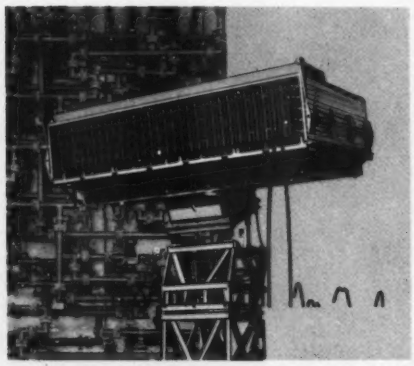

The antenna on our cover is shown superimposed over the network of feed lines and power dividers that constitute its so-called "corporate structure".

INVENTIONS

Congratulations to the following persons for their valuable contributions to Raytheon's portfolio of inventions:

Name	*Field of Invention*
Kermit Atlas	Igniter Charge
Colin Bowness	Raytheon db Rule
Colin Bowness, John Q. Owen	Waveguide Structure
Merle R. Boyd	In-Line Transition
David A. Copson	Microwave Dehydration of Food
Richard P. Curtis, Leonard B. Emerson	Meter Dial and Window
James C. Davis, Jr.	Frequency Multiplier
Robert V. Decareau	Temperature Control of Dielectric Material
Robert V. Decareau	Moisture Determination
Palmer Derby, L. W. Geier	Magnetron Assembly and Design
Gim P. Fong, Robert Davis	Ablation-Cooling Materials
Delbert L. George, Robert O. Howe	Hydrosqueegee Press
Thomas A. O. Gross	Solar Power Collector
P. Roland Hanson	Cavity Resonator Tuning
Robert Harper, Robert M. Unger	Pushing Elimination
Harold M. Hart	Microwave Platform
Edward G. Johnson	Ferrite Slab Rotator
Donald H. Keagan	Resistance Furnace
Max C. Mohr	Ferrite Modulator
John M. Osepchuk	Traveling-Wave Tubes
John Reed	Waveguide Harmonic Filter
Louis H. Schall, Jr.	Microwave Energy Coupling
Marshall Sirvetz	Resonance Absorption Isolator
Sumner P. Wolsky	Ion Catalysis

Calendar

ENGINEERING SEMINARS

Seminars will be held every other Tuesday at 4:45 P.M. in various laboratory cafeterias. Security clearance will be required as indicated. Personnel who do not hold picture badges should consult their security officers for attendance arrangements.

"The Electronic Components and Devices Group — Its Products and Plans"	March 15	Unclassified
H. R. Oldfield, Jr., Group Vice-President, Electronic Components and Devices	Spencer Lab Cafeteria	
"The Generation of Super Power at Microwave Frequencies"	March 29	Confidential
W. C. Brown, Microwave & Power Tube Div.....	Wayland Lab Cafeteria	
"Airborne Equipment Engineering Capabilities and Techniques"	April 12	Confidential
T. R. Silverberg, Airborne Electronic Equipment Operations	Sudbury Lab Cafeteria	
"Raytheon's Future in Weapon Systems"	April 26	Confidential
Martin Schilling, Office of the Group Vice-President, Government Equipment & Systems.....	Wayland Lab Cafeteria	

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Techniques for Ultra-High Temperature Systems ..... *J. F. Ahearn, L. F. Kilham, R. R. Ursch*..... 17

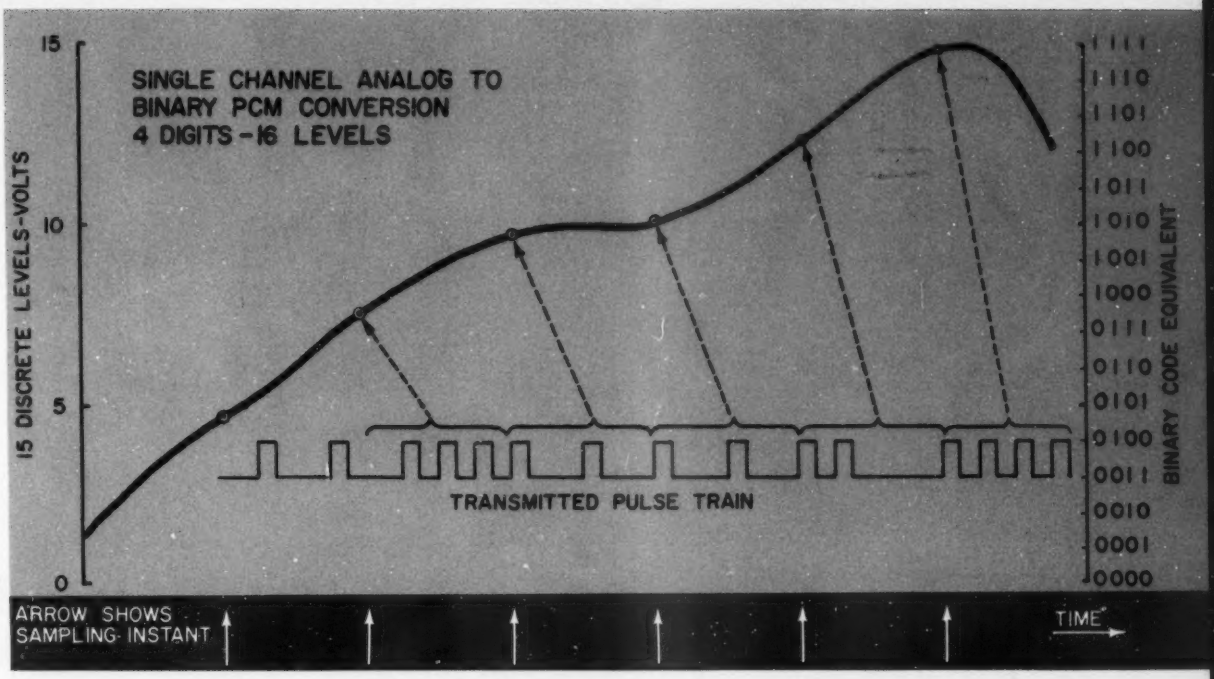


Figure 1

A NEW 96-CHANNEL PCM SYSTEM

J. Mofenson
Equipment Division

THE transmission of continuous information by means of pulses is becoming increasingly important in communications. Significant improvements in signal-to-noise characteristics, simpler radio transmitters and receivers, and better over-all system performance have been achieved with pulse modulation techniques. These techniques include pulse-amplitude, pulse-position and, more recently, pulse-code. Each of these techniques has in common the ability to transmit the necessary information on an intermittent basis in a small percentage of the total time required by the original signal. Using pulse modulation, it is also possible to transmit many signals over a single circuit by sequentially commutating each of the signals. A process of sampling is used to generate a pulsed signal to represent the amplitude of the voltage being sampled. Channel separation is maintained by allocating a different interval of transmission time to each channel. This is called time-division multiplex.

Of the pulse modulation systems being developed today, by far the greatest efforts are in the field of pulse-code. This type of modulation possesses many technical as well as economic advantages which make it extremely attractive for both military and commercial purposes. The use of pulse-code modulation (PCM) for transmission of voice-frequency signals is one of the basic requirements of many future communications networks.

The choice of PCM as a technique for modulating and multiplexing in communications links is based on a compromise between many factors. Among these are available bandwidth; size, cost and power requirements of terminal equipment; cable attenuation; repeater cost; signal-to-noise ratios; drop and insert facility; number of circuits; crosstalk, etc. Military needs superimpose additional requirements such as weight, serviceability, and message security. Other practical considerations, ranging from capability of radio-relay equipment to the necessity of system message compatibility with digital data originating from computers, must also be evaluated.

Raytheon at the present time is developing for the U. S. Signal Corps a 96-channel fully-transistorized PCM system for cable and radio transmission. A developmental model of this system (AN/TCC-37 and AN/TCC-41) will be completed in 1960. A brief description of the system will be presented as part of this consideration of those properties of PCM that make it a major method of communication.

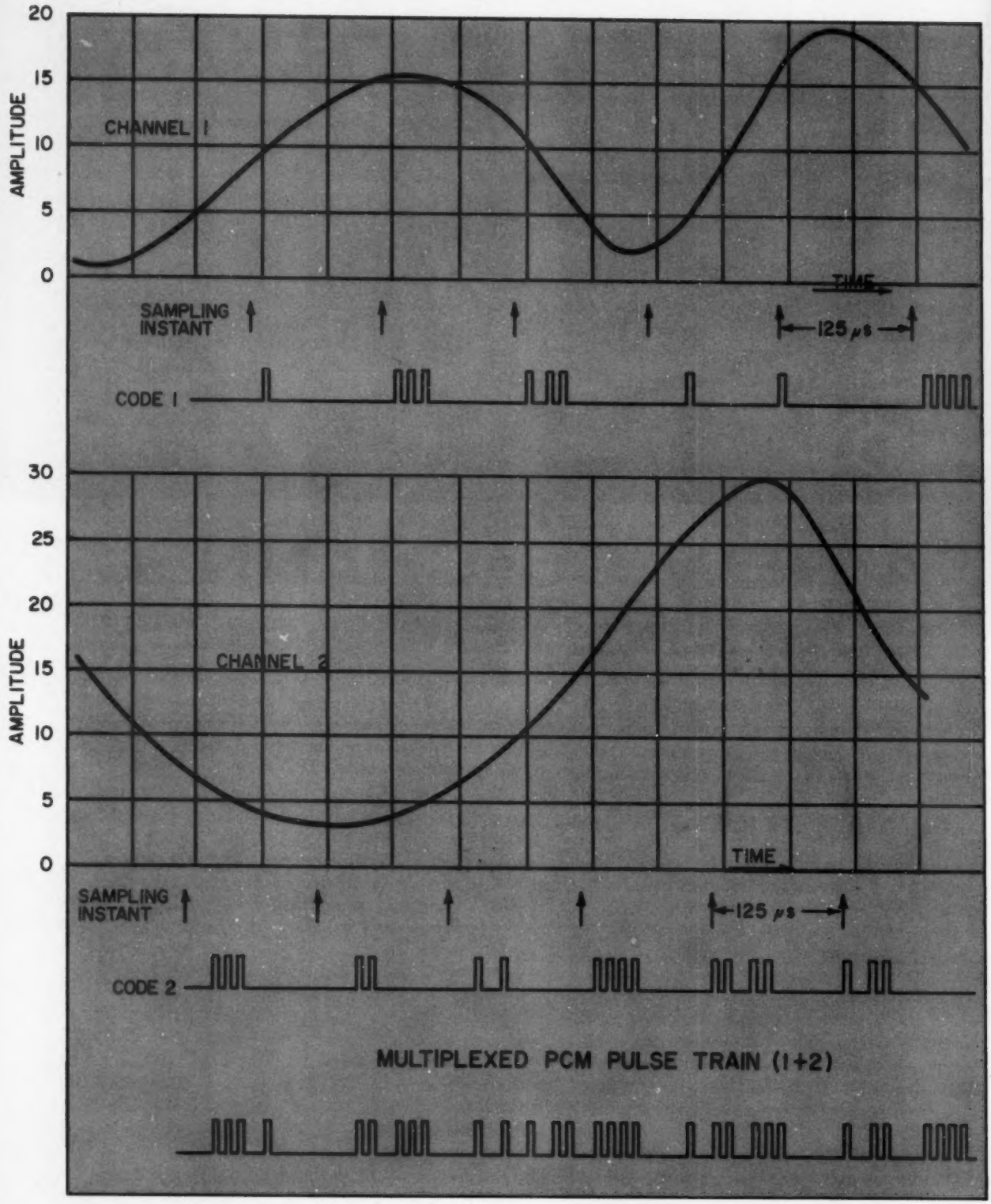

20
15
10
5
0
AMPLITUDE
CHANNEL 1
TIME
SAMPLING INSTANT
125 μs
CODE 1
30
25
20
15
10
5
0
AMPLITUDE
CHANNEL 2
TIME
SAMPLING INSTANT
125 μs
CODE 2
MULTIPLEXED PCM PULSE TRAIN (1+2)

Figure 2

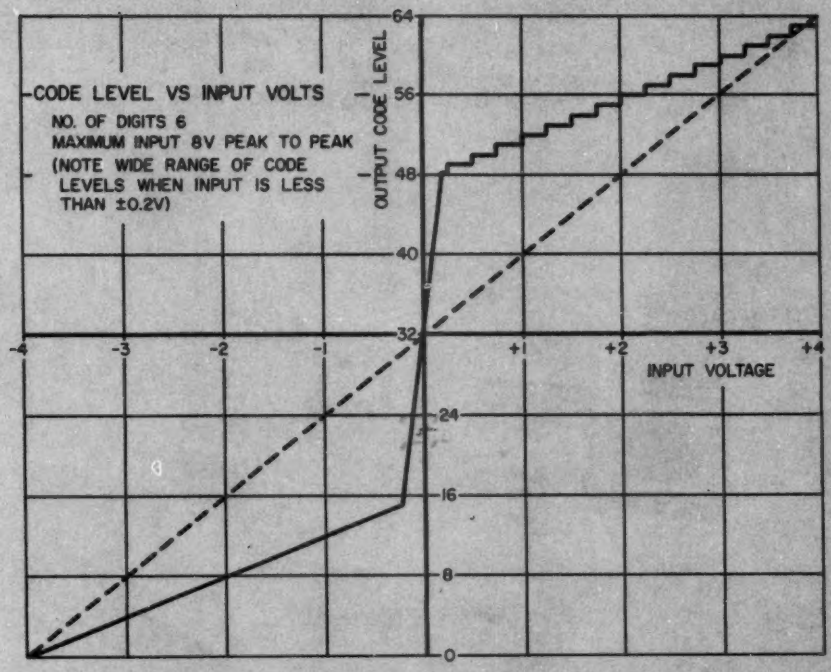
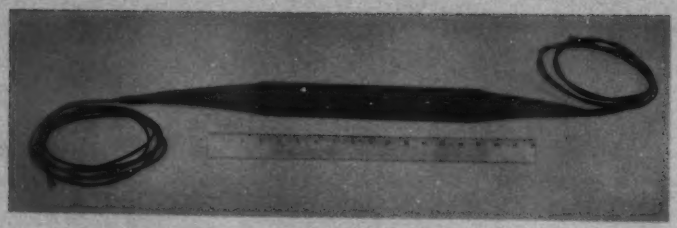

CODE LEVEL VS INPUT VOLTS
NO. OF DIGITS 6
MAXIMUM INPUT 8V PEAK TO PEAK
(NOTE WIDE RANGE OF CODE LEVELS WHEN INPUT IS LESS THAN ±0.2V)
OUTPUT CODE LEVEL
64
56
48
40
32
24
16
8
0
-4
-3
-2
-1
+1
+2
+3
+4
INPUT VOLTAGE

Figure 3



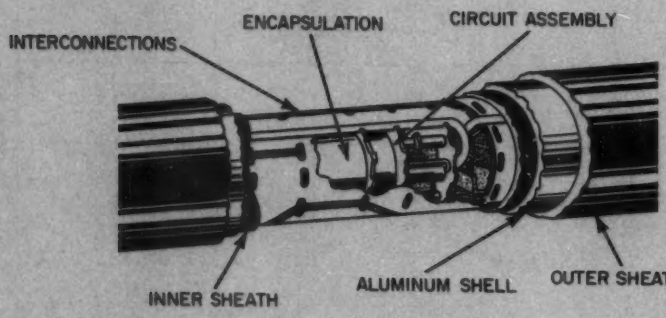
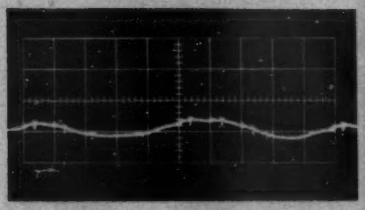


Figure 4



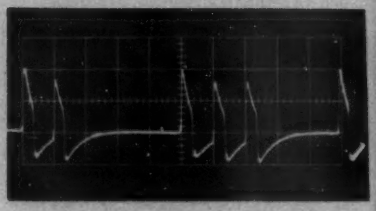


Figure 5

Signal Coding

In a typical multiplex PCM system, the incoming channels are sequentially sampled by an electronic commutator operating at 8000 cps. The output signal of the commutator is thus made up of amplitude samples of each of the incoming channels. The time duration of each of these samples is (125/n) microseconds, where n is the number of channels and 125 microseconds is the commutator period. This composite sampled signal is then fed into a coding circuit which converts it into a code combination of pulses and spaces corresponding to the incoming signal amplitude.

The amplitude sample is usually binary coded, and a number of pulses from 1 to 6 in any of 64 sequential combinations are generated for each sample. The interval provided for this series of coding pulses corresponds to the sampling interval. For example, in a 48-channel system which uses a 6-digit binary code, the sampling interval is 125/48 or 2.6 microseconds. A maximum of 6 binary digits or pulses are generated during this interval. If all digits were present in the pulse train, the pulse-digit period would be 2.6/6 or 0.43 microseconds. The resultant pulse train therefore consists of a train of pulses whose basic rate is 8000 x 48 x 6 or 2.304 mc.

Since a binary conversion permits only a finite number of values, the pulse-code representation must be rounded off to the nearest whole number. For example, in a system using a 6-digit code, the incoming signal can be coded to an accuracy of one part in 64. This results in a quantized-type signal which limits only slightly the fidelity of the intelligence being transmitted. There is an additional contribution of granular noise (not serious, however) due to the number and size of the quantum steps. For ordinary voice communication, a 6-digit code will result in a good-quality circuit.

For such a circuit it is necessary to obtain samples of tones as high as 3500 cps. If the sampling frequency is at a regular rate greater than twice the highest frequency transmitted and if the sampling interval is sufficiently brief, the samples contain all the information of the original signal. Thus, for voice-frequency circuits, a sampling frequency of 8 kc is usually chosen.

A rather simplified illustration of the coding principle is shown in Figure 1. A single-channel system and a 4-digit binary code have been selected for clarity. The amplitude of the input signals has been chosen to vary from zero to almost maximum modulation. The illustration shows the many different binary codes generated for each waveform during the sampling process. (Figure 2 shows the coding and multiplexing of two channels. Here a 5-digit code is used.) The multiplexed train shows the combined pulse configuration output from each channel on one wire. For the example shown, the amplitude fidelity is no better than one part in 32.

In PCM using binary code, the transmitted pulses are of equal amplitude and duration. The basic digit rate of the pulses is usually determined by a crystal-controlled master clock. Timing signals for the commutator, the sampler, and all the multiplexed channels are derived by counting down from the master clock, thus resulting in a completely internally-synchronized system. To demodulate the signal at the receiving terminal, it is necessary to regenerate the digit frequency, to establish frame and channel synchronization, and to determine the presence or absence of ones or zeros (pulse or no-pulse).

The process of frame synchronization causes the PCM receiver to re-establish the timing sequence generated by the transmitter and to properly identify each of the channel groups. Practical PCM systems use one digit or time slot in each frame for synchronization. This digit resembles the others in amplitude, position, and shape, and can be recognized only by the fact that its presence or absence is in accord with the predetermined synchronization pattern. Channel and digit synchronization are also required prior to demodulation. Here each of the channel code groups is separately decommutated, and the resultant signals passed into digital-to-analog converters where the original voice-frequency signals are recovered.

The previous discussion has been based on the use of a binary-coded (2-level) PCM system. PCM systems using 3-, 4-, or 8-pulse levels are quite feasible, and in fact require proportionally less bandwidth. However, although binary systems require the maximum bandwidth of any PCM system, their transmission and repeater requirements are more lenient, and the encoding and decoding circuits are more reliable. Binary PCM is used throughout the cable system in the Signal Corps system under development. Ternary PCM is used in some parts of the radio system.

Properties of PCM

PCM has certain inherent properties that make it a desirable choice of modulation for multiplex telephony. As with frequency modulation, the structure of a PCM signal is not affected by amplitude variations during transmission. Impairment within tolerable limits of the binary-level structure of PCM by noise, distortion, and interference results in negligible degradation of the received signal. Precision timing for the PCM train is obtained by a crystal-controlled clock which determines the transmitted pulse frequency. The receiver samples the incoming pulse train at fixed intervals and determines whether or not a pulse is present. Timing control is achieved

by a narrow-band crystal-filter in the receiver which selectively enhances all signals occurring at the proper rate.

Generation of the new timing waveform is most effectively achieved by a complete re-timing process which synthesizes the generating clock-frequency waveform. This may be accomplished by a high-Q crystal-controlled resonant circuit. Input excitation for this circuit is initiated by amplified digit pulses in the PCM train. The impulse response of the tuned circuit is such that sufficient energy is present to maintain a continuous clock output even in the presence of noise or random absence of pulses. By re-combining the input pulse train with the clock-frequency waveform, a new pulse code train is generated. The instants of pulse regeneration are determined principally by the clock-frequency signal, and no accumulation of timing errors results. In cable transmission, the PCM pattern can be detected in the presence of noise and interference which may be a large percentage of the pulse amplitude.

Another advantage of PCM is that it permits the use of simple regenerative repeaters in a transmission circuit. The nature of the signal and the detection circuits in each link prevent the accumulation of signal degradation and noise contributed by the link. Normal transmission attenuation can then be overcome by inserting repeaters in the circuit. Each repeater is capable of complete signal regeneration. Thus, the entire allowable signal distortion of a system can be borne substantially by any one link without the effect being cumulative.

The digital nature of a PCM signal permits any number of pulse transpositions to be made in the signal pattern. The military advantages of this capability to provide a very high degree of message security are self-evident. By the application of coding using computer techniques, an entire multiplexed message may be put into cryptographic form simultaneously.

Companders

PCM encoding and decoding of speech provides good fidelity for ordinary talkers. When low speech levels are used, however, there is a degradation of the circuit performance because the number of possible code levels is small and distinctions between levels are not adequately coded. To overcome this difficulty, a pair of carefully devised non-linear circuits is placed at the PCM terminals at points immediately preceding encoding and following decoding. At the coder, the circuit expands low amplitude signals and compresses high amplitude signals. The reverse procedure is accomplished at the decoder. This process, called instantaneous companding, is of vital importance in achieving high quality circuits. Only one companding network is required for an entire PCM terminal. Figure 3 shows the input-output characteristics obtained using a compander. Note that for signals having a peak to peak value of 0.4 volts or less, the amplitudes are represented by 32 code levels. Without companding, this range would be represented by only 3 levels.

An additional factor which makes the use of PCM for voice circuits important is the fast-growing traffic requirement imposed on communications circuits by high-speed digital data. Since electronic data-processing signals are almost universally in the form of

Publications & Papers

H. AHLBURG, W. T. ERIKSEN, R. ZALLEN, "Electroluminescence and Pulsed Square Wave Excitation," presented at the APS Meeting in New York on January 30, 1960.

R. BRAUNE, M. SILBERBERG, R. H. SUPNIK, "Effects of Rate of Loading on Shear Stress of Metal-to-Metal Bonds," presented at the First NATEC Meeting of the Society of Plastics Engineers in Los Angeles on October 14, 1959.

W. C. BROWN, "The Practical Utilization of Power Transmission by Electromagnetic Beams," presented at the IRE-PGED Meeting in Boston on October 26, 1959.

W. C. BROWN, "The Generation of Super Power at Microwave Frequencies," presented at the NEREM Convention in Boston on November 19, 1959.

W. C. BROWN, M. THEODORE, "Practical Utilization of Microwave Energy for Microwave Propulsion," presented at the IRE-PGED Meeting in Boston on November 23, 1959.

W. C. BROWN, "The Amplitron and its Applications," presented at the U. S. Naval Post Graduate School in Monterey on December 4, 1959.

A. R. CHAUDHURI, J. R. PATEL, "Effect of Initial Dislocation Density on the Plasticity of Germanium," presented at the AIME Meeting in New York on February 17, 1960.

A. R. CHAUDHURI, J. R. PATEL, "Yield Behavior in Germanium," presented at the AIME Meeting in New York on February 17, 1960.

J. E. CLINE, S. J. SOLOMON, "Vibratory Polishing and Lapping of Semiconductor Materials," presented at the Fall Semiconductor Symposium (Electrochemical Society) in Columbus, Ohio on October 22, 1959.

D. DAS, D. PITMAN, "A Study of the Thorium-Tungsten-Boron System," published in the JOURNAL OF THE ELECTROCHEMICAL SOCIETY, May, 1959.

R. C. ELLIS, JR., "Some Etching Studies on Boron T-191," presented at USASCRDL in Asbury Park, New Jersey on September 18, 1959.

R. C. ELLIS, JR., "Various Preparations of Elemental Boron," presented at USASCRDL in Asbury Park, New Jersey on September 18, 1959.

P. X. FLAHERTY, "Metallurgical Analysis of the Bulk Diffusion Phenomenon in Silicon Power Transistors," presented at the Fall Semiconductor Symposium (Electrochemical Society) in Boston on October 22, 1959.

J. J. GREEN, U. MILANO, E. SCHLOMANN, "Recent Developments in Ferromagnetic Resonance at High Power Levels," presented at the IRE Conference on Magnetic Materials and Magnetism in Detroit on November 16, 1959.

M. A. JONES, "Pulsed Sequential Circuits Using Laddics," presented at the NEREM Meeting in Boston on November 19, 1959.

J. S. MACDOUGALL, "Conversion Curves Allow the Use of Average Reading Meters on Chopped Waveforms," published in ELECTRONICS, December 25, 1959.

J. S. MACDOUGALL, H. F. STARKE, "Transistor Noise at Low Frequencies," presented at the Audio Engineering Society Convention in New York on October 5, 1959.

R. E. SEIFERT, "The Semiconductor," presented at the IRE Diode Lecture Series in Boston on October 6, 1959.

S. B. SMITH, "Buying in Fluctuating Markets," published in PURCHASING, December 7, 1959.

S. B. SMITH, "Solving Mix Problems with Linear Programming," published in PURCHASING, December 21, 1959.

S. P. WOLSKY, E. J. ZDANUK, "The Ion Bombardment, Oxidation, and Regeneration of Germanium Surfaces," presented at the Second Conference on Semiconductor Surfaces at Silver Springs, Maryland on December 3, 1959.

S. ZIERING, "Half-Range Collision Integrals for Maxwellian Molecules," presented at the APS Division of Fluid Dynamics Meeting in Boston on November 23, 1959.

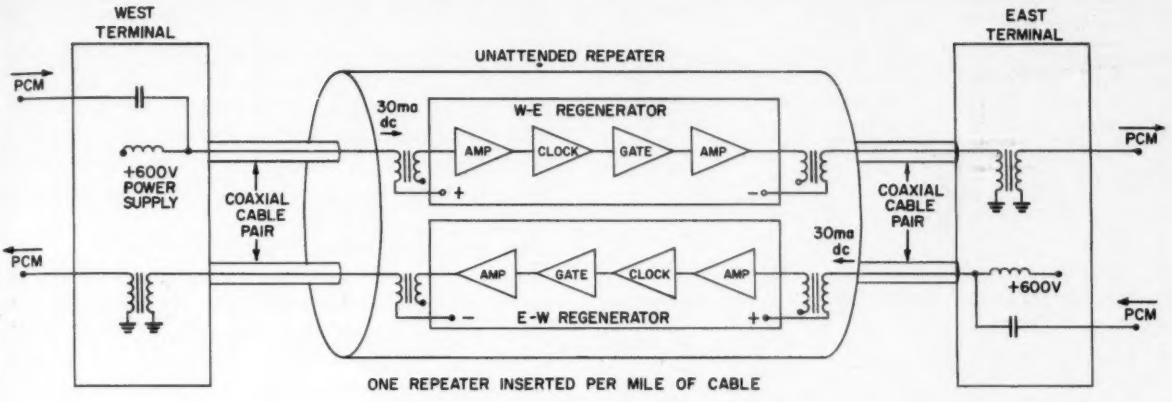


Figure 6

pulses, PCM meets the compatibility requirements of radio systems handling both voice and data traffic.

From an economy viewpoint, studies have shown that for large numbers of channels the cost of PCM terminal equipment per channel is less than for methods using single-sideband, suppressed-carrier frequency-division multiplex (FDM). This advantage derives from the pulse nature of the PCM signal, from the lack of requirements for distortion-free amplification, and from the avoidance of costly channel filters. Crosstalk and channel loading are also more favorably handled in PCM. The promises of smaller, lighter, and less expensive terminal equipment to be realized by the use of PCM provide the remaining factors which have sparked large military and commercial ventures in this field.

These desirable characteristics are obtained in exchange for increased bandwidth. A 6-digit binary PCM system for voice communication requires a minimum video bandwidth of 24 kc per channel. This is six times that of conventional FDM terminals. Radio frequency bandwidth is usually available in many FDM microwave systems to accomodate 96 channels or more. The use of PCM for modulating radio transmitters is quite practical. In cable systems, the required bandwidth can usually be achieved by simple equalizers. Phase requirements for the upper part of the frequency spectrum are not as severe as those imposed by FDM.

96-Channel PCM System

In the system being developed by Raytheon for the Signal Corps, two types of equipment are required. One type provides the terminal equipment suitable for transmission of multi-channel voice and data over radio-relay, and the other provides a complete 40-mile repeatered cable-transmission network for the same type of traffic. Both systems will integrate into the Army ground-communications network. In the cable system, repeater amplifiers (which provide a means for regeneration of the signal as it travels down the line) will be inserted into the system at 1-mile intervals. A photograph of the repeater and a sketch showing its internal construction are presented in Figure 4. As many as 40 of these ruggedized repeaters may be used in any link between attended points. Tactical needs require that the entire cable system can be dropped from a helicopter and be operable even when submerged. When put into operation, the system permits the interconnection on a 4-wire basis of digital signals into standard Signal Corps radio and wire circuits. When used with radio links, the system will provide all the terminal facilities for multiplexing up to 96 voice channels. Using cable, the total capacity is 48 voice channels.

The telephone terminal accepts 12, 24, 48, or 96 voice-frequency signals, samples each one in sequence at 8000 cps, combines the resultant pulse-amplitude samples on a time-division basis, codes these samples in a 6-digit binary code, and transmits the coded signal over the pair of coaxial cables or to the input of the radio-relay set. In addition, the terminal accepts the incoming PCM pulse train from the cable or radio, decodes these signals, and distributes them to the proper voice channel. Provisions for handling two data channels are included.

In the cable system, the unattended repeaters include circuits to completely re-time the received pulse train in both directions of transmission and to condition the pulses for re-transmission. In this process, each received pulse is replaced by a new one, standardized in timing, magnitude, and pulse shape, thus eliminating the accumulation of distortion due to noise and bandwidth limitations. Figure 5 shows the oscillogram of a series of pulses in a 1100111 configuration before and after processing by the repeater. A total of fourteen transistors are used in the repeater.

Power for the repeaters is obtained from a constant-current supply located in the terminals using the center conductors of the coaxial cable. Figure 6 shows the power supply loop for the unattended repeaters. Provision for fault location at the attended points to

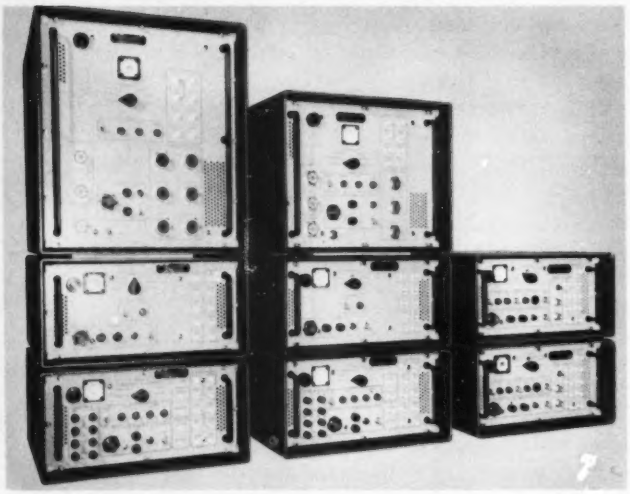


Figure 7

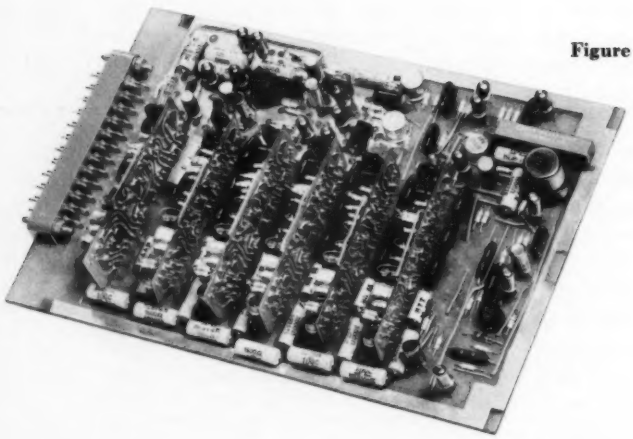
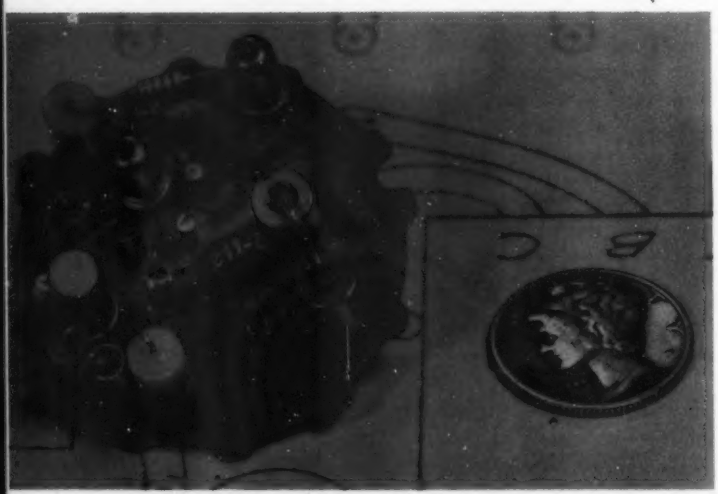


Figure 8



pinpoint damaged units is also included. Order-wire facilities for service personnel are derived by multiplexing the voice signal on a frequency-division basis with the PCM train. This is accomplished by transmitting the voice-frequency signal directly over the cable by using the conductor and the sheath as a pair of wires.

Major components of the system are multiplex telephone terminals, regenerative repeaters, and unattended coaxial cable repeaters. Auxiliary equipment is provided to permit combining pairs of multiplexers to give the higher traffic capability of each system, and to condition the signals for transmission over cable or radio links as required. Other units comprise a lineman's test set to be used for cable maintenance and a unit to drop or insert one-half of the maximum number of channels. Figure 7 shows terminal multiplexers for high and low traffic, combiners, and attended repeaters.

The equipment being developed for the Signal Corps is completely transistorized and utilizes many novel circuit and packaging techniques. High-speed switching transistors and diodes are used extensively. Modular techniques embodying potted circuits are used throughout the equipment. Special care has been given to the selection and inspection of components and to ease of maintenance, since it is expected that this equipment, once in operation, will remain in continuous, round the clock service. The engineering test models will meet all the rugged environmental conditions imposed upon Signal Corps' field equipment operating from −40°C to +60°C.

The component density will be unusually high, and the equipment is being designed to permit rapid performance checks by inexperienced operators. There will be a minimum of front-panel adjustments. In the event of malfunction, trouble areas can be isolated through the use of an internally mounted test facility, thus permitting rapid replacement of plug-in cards. Figure 8 is a typical plug-in card showing modular-type mounting. In production units, modules will be encapsulated to insure rigidity and protection to the components. The component count for a single high-traffic terminal is approximately 14,000, of which 2,300 are transistors. All the components used in the 96-channel equipment will have received military approval.

Upon completion, the Raytheon 96-channel PCM system will represent an important contribution to the field of multi-channel voice communication. It will provide a modern, highly efficient telephone link to meet increasing military traffic requirements while at the same time achieving small size, light weight, and high reliability. The system is expected to find important usage in future military communications networks.

THE CORPORATE STRUCTURE ANTENNA

A. M. McCoy, C. F. Winter
Equipment Division

EXTENSIVE development work has been conducted at Wayland Laboratory in recent years on an extremely versatile type of microwave antenna known as the corporate structure. The name is derived from the resemblance between the circuit diagram of the antenna feed system (Figure 1) and the organization chart of a business corporation. The power from a single input feed line is distributed among the radiating elements of the antenna by a network of power dividers. The nature of the radiated beam is determined by the number and type of radiating elements and by the phase and amplitude of the energy at each element. The fundamental advantage of the corporate structure is the high degree of control which can be exercised over the radiation from each of the elements of the antenna.

The price paid for this control is complexity. When the number of radiating elements is small, the corporate structure is correspondingly simple. As they increase in quantity, the number of components in the corporate structure rapidly becomes astronomical. As we approach, say, 100 elements, the mechanical engineers are shuddering at the weight involved, the customer dares not think what the cost will be, and everyone is wondering how it can ever be put together. All of these are valid objections and can be outweighed only by operational requirements which cannot be satisfied by any of the more conventional antenna designs.

Corporate Structure Components

The key components of the corporate structure antenna are the power dividers and the radiating elements. A clear understanding of the power divider is essential to an understanding of the antenna.

Consider a power divider with a single input and two outputs (Figure 2). Ideally, this tee should be capable of splitting the power in any predetermined ratio without any loss in power. Furthermore, this ratio should be unaffected by frequency or by the terminations on the output lines. We have been able to approach all but the last of these conditions using a tee developed by John Reed and Gershon Wheeler at Wayland Laboratory. The power division ratio is determined by the diameters of the inner conductors of the coaxial transmission line making up the tee. The device is relatively insensitive to frequency changes because the ratio is controlled by the charac-

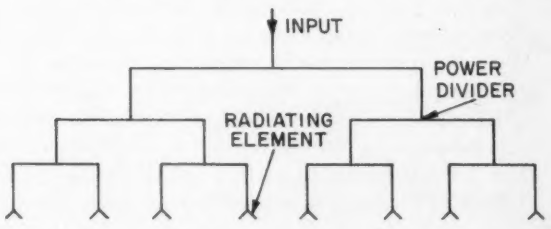


Figure 1

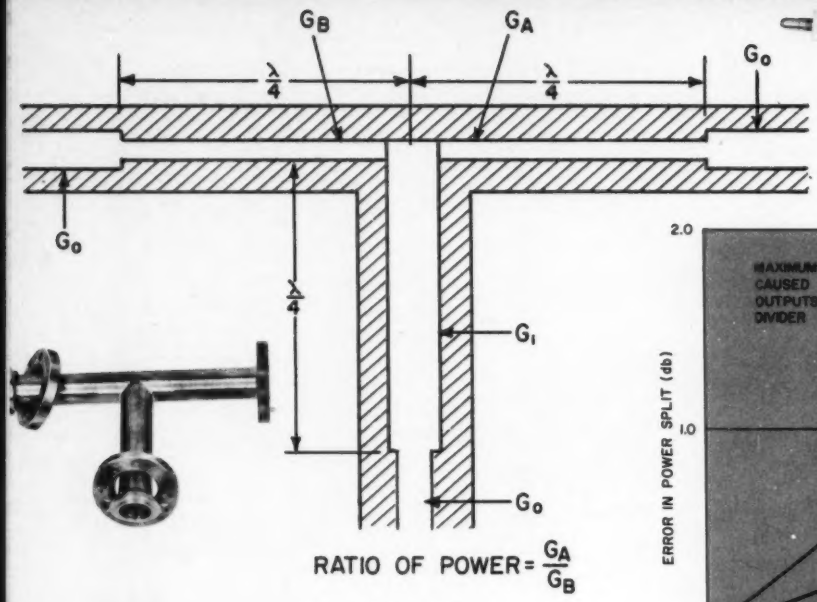
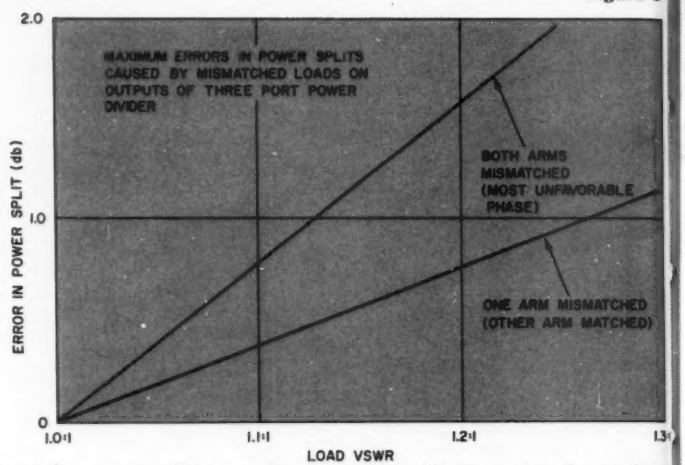


Figure 2

Figure 3



teristic impedance of the lines. Some frequency dependance is introduced by the quarter-wavelength sections of line which are used as transformers. The power in each output arm is V_J^2G, where V_J is the driving voltage at the junction of the tee and G is the conductance looking into the arm. Since V_J is the same for both output arms, the power ratio is simply G_A/G_B. If both arms are terminated in reflectionless loads, the power ratio is fixed by the line diameters.

In a real situation, voltage-standing wave ratios, r_A and r_B will be present in each line. The conductance of line A will vary between the limits $G_a \times r_A$ and G_a/r_A, where G_a is defined as the characteristic conductance of line A at the junction of the tee. The value of G_a within these limits is determined by the phase of the reflected wave. When $r_A = r_B$ and the reflected energy in both lines has the same phase, the power division ratio is undisturbed by the reflections. This occurs whenever identical discontinuities are equidistant from the junction. When these two conditions are not met, the ratio is disturbed. Even small reflections can cause large errors, as shown in Figure 3.

This places severe requirements on the design of the corporate structure because the distribution of energy among the radiating elements is correct only when the lines are reflectionless or when the reflections are of the special character described above. On the other hand, the device for controlling this distribution has the important advantage that it is relatively insensitive to changes in frequency. Broadband operation is seen to be characteristic of the corporate structure.

Although it is not necessarily a basic limitation, generally a corporate structure is used to feed a line of radiating elements. This linear array determines the beam in one plane; the beam in the other plane is formed quite independently by the radiating elements, by a reflector, or even by an array of second corporate structures. We shall concentrate on broadside linear arrays: that is, arrays with all elements fed in the same phase so that the beam is normal to the line of radiating elements. Arrays fed by corporate structures with the elements phased to produce an oblique beam are quite feasible and have been discussed to some degree in the literature.

Broadside arrays are of primary interest here because the power division ratios are not disturbed by the fact that the radiating elements are not reflectionless terminations or by the fact that some of the radiated energy is coupled into adjacent elements. In the broadside case the radiating elements fed by a particular power divider are all electrically equidistant from that divider. The reflections from the radiators are identical in phase and amplitude, then, if the radiating elements are identical. Mutually coupled energy also has the properties of reflected energy. This arrives in phase at each tee and, except for elements near the end of the array, the equivalent reflection coefficient is the same at all tees. (This assumes that the amplitude distribution from the center to either end of the array is monotonic.) Thus the special conditions for reflected energy that does not alter the power division ratios have been met.

Since the radiating elements do not contribute to errors in the power distribution, we need only contend with reflections within the corporate structure. In many applications the tees cannot be equally spaced from each other; in addition, the transmission lines joining the tees are neither identical nor reflectionless.

Errors within the corporate structure being inevitable, we are confronted with the problem of designing the corporate structure so that the undesirable effects of these errors on the radiated beam are minimized.

Corporate Structure Design

In the case we have selected — the broadside linear array — the phase distribution is already designated: all elements are in phase. The amplitude distribution is yet to be chosen. Many choices are open to the antenna designer employing the corporate structure feed which are simply not feasible with other antenna types such as the reflector fed by a horn.

One such possibiilty is uniform amplitude distribution. This has the advantage that, for a given antenna length and wavelength, the beamwidth is minimized. Another type is the Dolph-Tchebyscheff: for a given wavelength, antenna length, and beamwidth, the minimum side lobe level is achieved. Much of our work has been with the Taylor distribution, which is similar to the Dolph-Tchebyscheff. While slightly less efficient, the Taylor type has the characteristic that the side lobes decrease in magnitude as the angle from the main lobe increases, whereas all side lobes are equal in magnitude for the Dolph type. Regardless of the choice made, it should be noted that there is high aperture efficiency (roughly defined as the ratio of antenna length to beamwidth, wavelength being fixed), and that low side lobes may be realized.

It is essential that the corporate structure be designed to avoid periodic errors. Such errors may occur when, say, every fifth element of the array is fed from a single power divider. The effect would be exactly that of the superposition of an array with an inter-element spacing five times that of the basic array. This new array, because of the wide spacing, has several principal maxima, all but one of them being off the axis of the main beam. These maxima show up as side lobes, which might well be excessively high.

By careful design, it is possible to build a high degree of randomness into the corporate structure. Figure 4 is an example of such a corporate structure, in this case an 80-element feed. The network is symmetrical about the center line with the elements being numbered from 1 to 40 from the center to either end. The number at each tee indicates the fraction of the input which goes to the upper output arm. This network yields the distribution shown in Figure 5, in this case the Taylor type for side lobes 40 db below the main lobe.

If we assume that the corporate structure does feed the array so that errors will be random, statistical

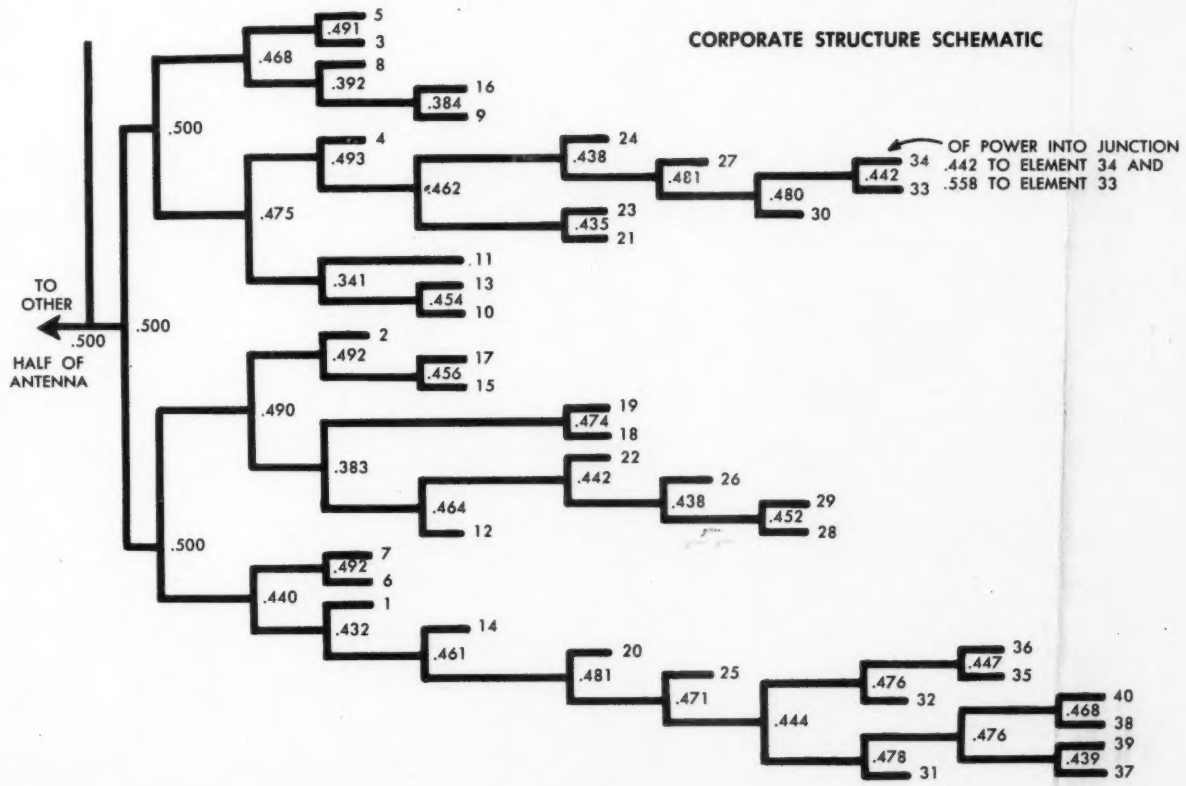


Figure 4

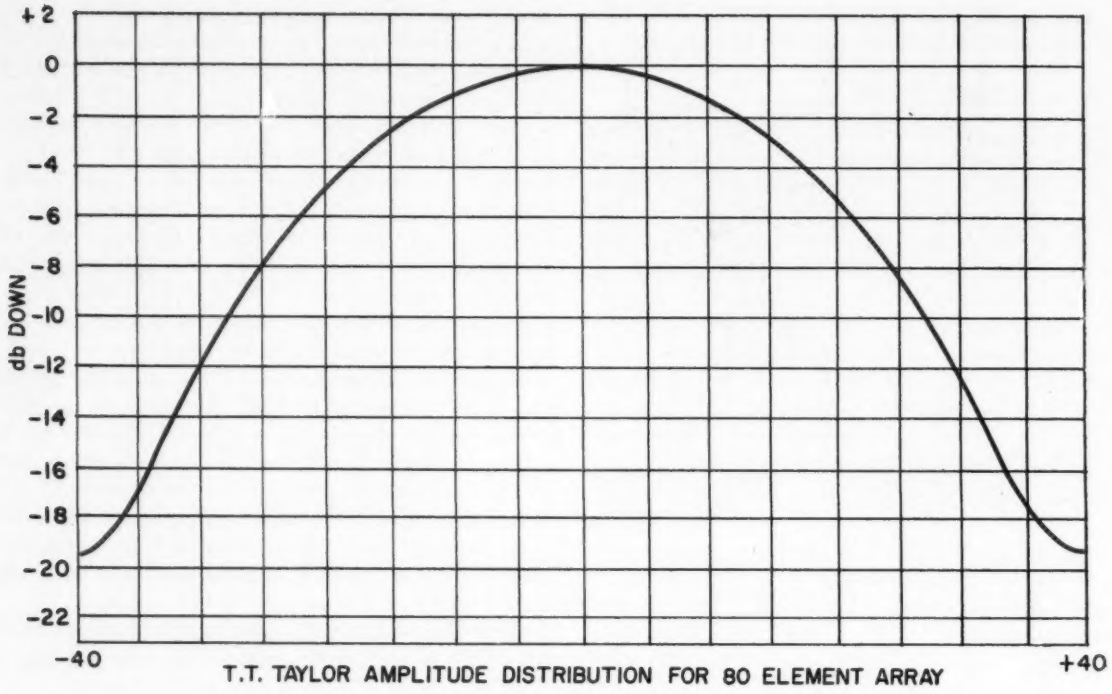


Figure 5

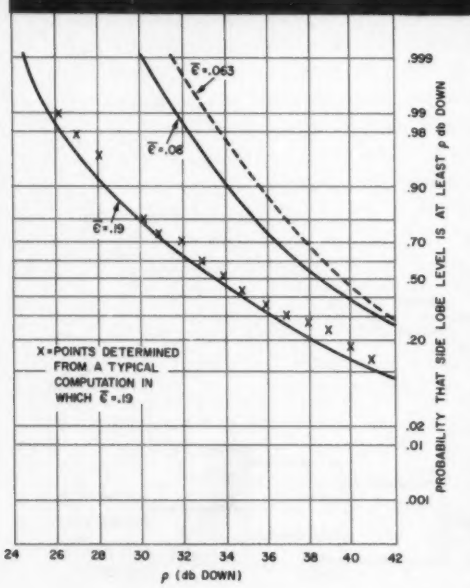


Figure 6

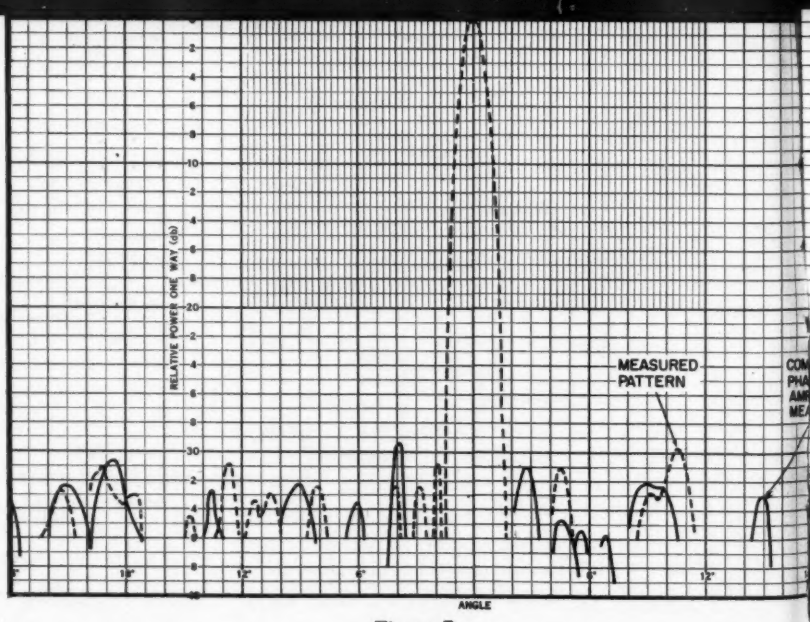
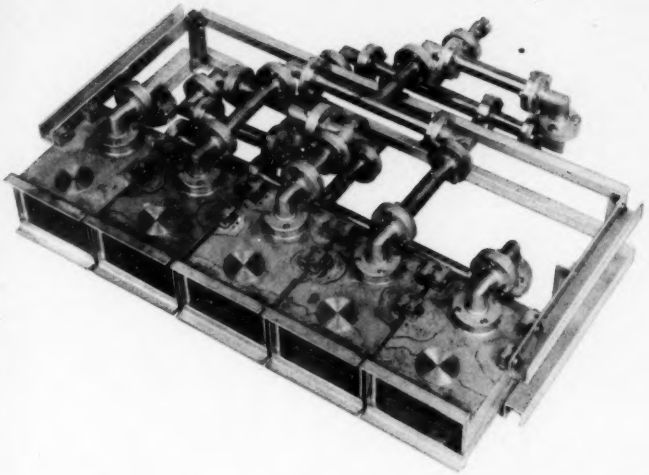


Figure 7



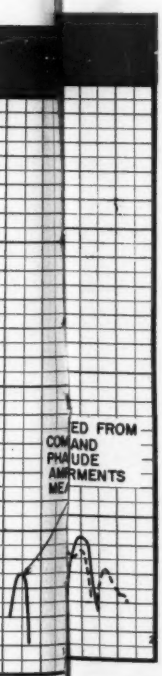
theory may be used to predict the side lobe levels which will occur. This is valuable because it enables us to translate antenna pattern requirements into design criteria for the corporate structure components. Furthermore, from measurements of phase and amplitude of the signal at each element of the array, the antenna pattern can be computed. This is often desirable when the large size of an antenna or the very low side lobe levels make antenna pattern measurements exceptionally difficult. Reasonable correlation between measured and calculated patterns has been achieved, as shown in Figure 7.

Capabilities and Limitations

To date at Wayland Laboratory our interest in the corporate structure has been concerned with its broadband, low side-lobe capabilities. We have made antennas with side lobes more than 32 db below the main lobe over a 30 per cent frequency band, and below 35 db over much of this band. Figure 8 is an example of the sort of patterns which have been measured. This performance is superior to that of a reflector for which 24 db side lobes and a 10 per cent band of operation might be typical.

The upper limit on bandwidth has not been determined, but is probably close to 40 per cent, a figure which is not far from the useful range of waveguide. Lower side lobes are also attainable, but no signficant improvements should be expected without a different type of power divider. A device is needed in which all reflected signals would be absorbed, rather than being bounced around inside the corporate structure and coming out as error signals.

The advisability of using a corporate structure antenna should be considered whenever the antenna designer is faced with requirements which cannot be met using ordinary techniques. But first — he must be sure he has a generous budget, a distant delivery date, and a group of indefatigable engineers.



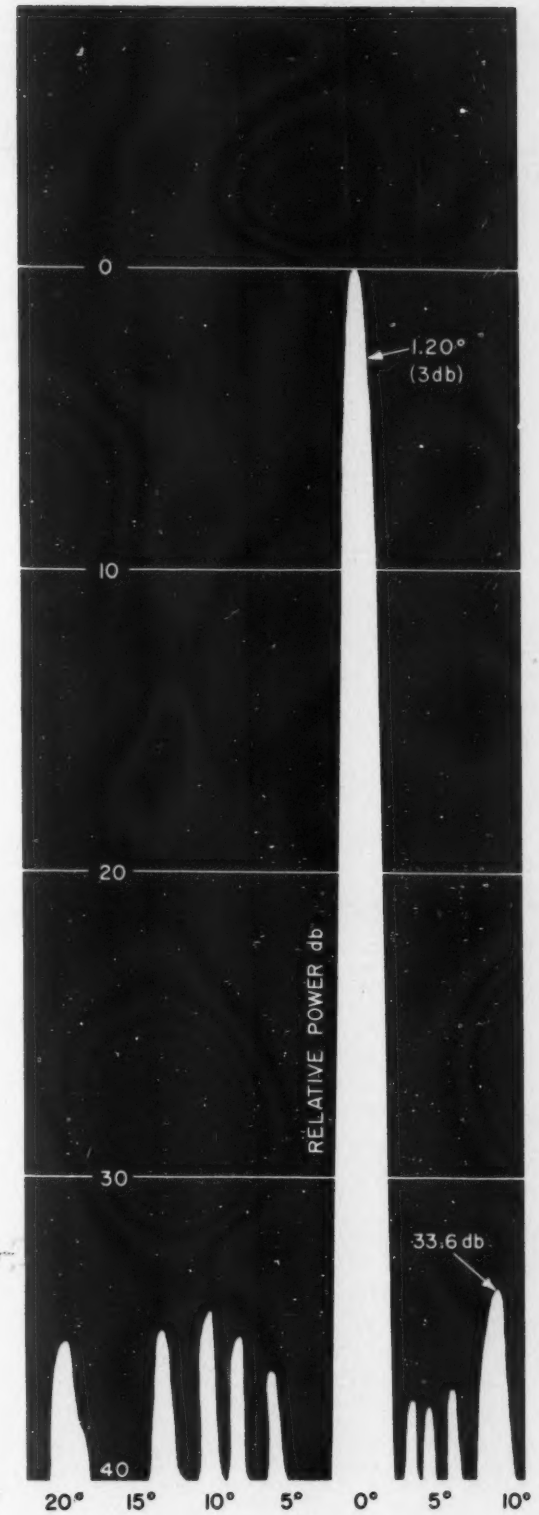


Figure 8

COZI

The Communication

RAYTHEON has for many years carried out a program of applied propagation research, particularly as related to propagation via the ionosphere, an ionized region in the upper atmosphere. This effort traces its beginnings largely to a project started in the late 1940's to develop for the Air Force a very long range ionospheric radar. One of the outgrowths of this work has been an oblique incidence sounding technique (commonly called COZI for COmmunication Zone Indicator) which enables a communication or broadcasting station to determine the regions which its transmissions are reaching. This article will review some of the basic principles of ionospheric propagation, describe the COZI technique as conceived using pulse transmissions, and then indicate some recent developments which enable oblique incidence soundings to be obtained with normal communication transmissions.

Review of Mechanism of HF Skywave Propagation

One way to communicate beyond the line of sight with electromagnetic radiation is to use an intermediate reflector or scatterer visible to both terminals of a circuit. Within certain limitations, the inosphere provides such a reflector (Figure 1).

The ability of an ionized region to reflect rays depends upon the density of the ionization and the frequency of the ray. Lower frequencies require less ionization for the same degree of bending; also, less bending takes less ionization. Maximum bending occurs when a ray is turned all the way back upon itself through 180 degrees. For a given degree of ionization, the highest frequency which can be bent through 180 degrees (and thus reflected vertically) is called the vertical incidence critical frequency. A slightly higher frequency will penetrate the layer when it impinges normally upon it, but can be bent back to the earth if it strikes obliquely. Of course this ray cannot be returned to the transmitter but will strike the earth some distance away. A still higher frequency must strike at even more oblique angles to be bent back, thus reaching the earth at even longer distances. This is illustrated in Figure 2.

The effect just described results in a skip distance which is the minimum distance along the earth's surface that can be reached by way of the ionosphere on a given frequency. Rays which would have reached shorter distances simply penetrate the layers instead of being reflected. In this simplified picture of the ionosphere, it is easily seen that there is a skip distance associated with each frequency higher than the vertical incidence critical frequency. Conversely, there is a maximum usable frequency associated with each distance. Therefore, to reach a given distance, it is essential that the frequency used be less than this maximum usable frequency, commonly called the MUF.

These ionized regions in the upper atmosphere are caused by a reaction of the constituent particles with incoming radiation, mainly from the sun. Although the mechanism is not fully understood, the ionization seems to occur in several discrete layers, possibly because different portions of the radiation spectrum produce ionization more efficiently at those levels of the atmosphere. The two most prominent layers are called the E and F layers, the F layer sometimes

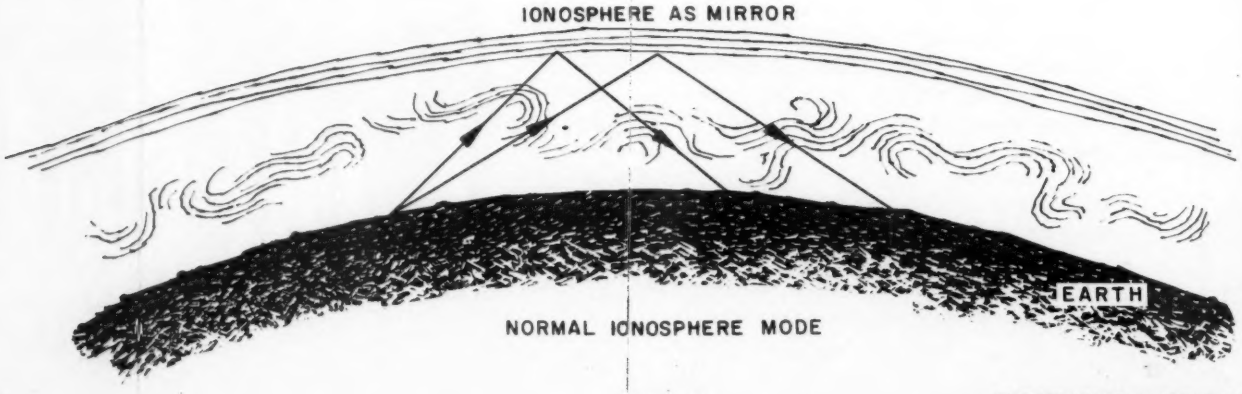


Figure 1

Zone Indicator

D. Hedlund, L. Edwards Equipment Division

being split into the F_1 and F_2. The E layer is normally about 100 kilometers and the F layer 200 to 500 kilometers above the earth. The F layer, being higher and in general more highly ionized, is more useful for long distance communications; however, the E layer is often useful for shorter circuits.

A complete description of these layers in the form of ionization density versus height can be very complicated and is beyond the scope of this discussion. A somewhat simpler and yet still useful description can be given in terms of the vertical incidence critical frequency and the virtual height of the various layers. A knowledge of these quantities is necessary to determine the MUF for a given path. These quantities are subject, however, to considerable variation: geographically, diurnally, seasonally, with respect to solar activity, etc. The general trends can be predicted, but there are apparently random day to day variations much like those in the weather which cannot be accurately predicted. Thus, the communicator must rely on the accuracy of the long range predictions issued by Central Radio Propagation Laboratory of the National Bureau of Standards, as well as on his own previous experience, or else he must try all available channels in choosing a frequency to establish a circuit. The technique to be discussed here provides an alternative to these methods.

Before describing this technique, one other point should be made. One might ask why a fairly low frequency chosen to be always below the MUF could not be used so that no consideration need be given to ionospheric variations. There are many reasons why this is not desirable or even possible in some cases. Let us mention only two of the more obvious ones. First, this would crowd all communications toward the lower frequencies leaving much of the useful spectrum idle. Interference would then be very serious since long and short distance circuits would be competing for the same frequency band. Second, the amount of absorption suffered by a ray is inversely proportional to the square of the frequency used. Thus, the highest possible frequency will give the strongest signal for a given amount of radiated power. Other factors such as multipath, antenna considerations, and privacy also suggest use of the highest possible frequencies.

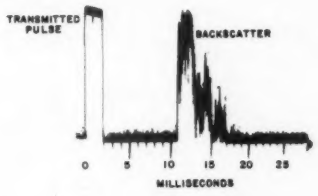


Figure 3

Ground Backscatter

Let us now turn our attention to the oblique incidence sounding technique. If a fairly short pulse is transmitted, the energy will be reflected from the ionosphere in accordance with the earlier discussion and returned to the earth at some distant point. Since the earth is not a smooth reflector but rather a scatterer, some of this energy is returned along the same ray path back toward the transmitter, arriving there some finite time later. The earliest arriving energy will have come very nearly from the shortest possible

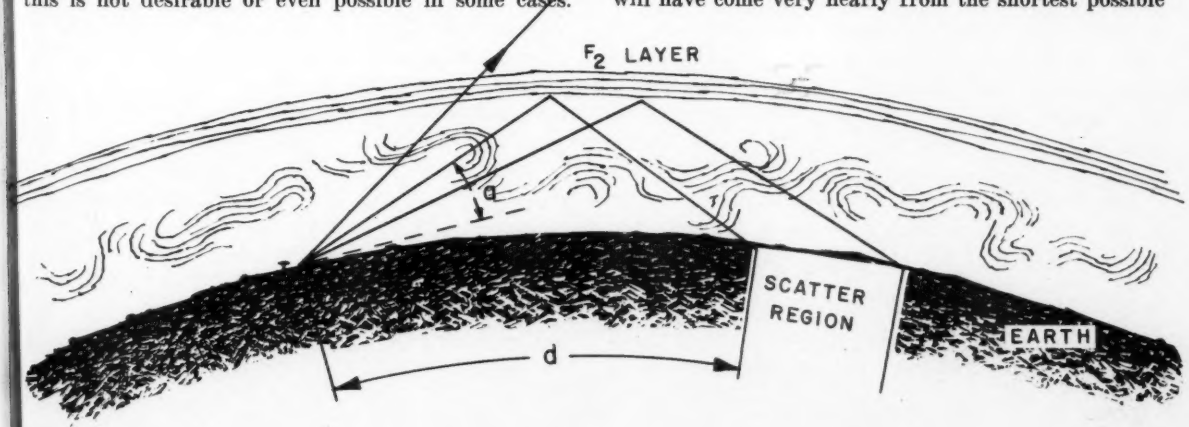


Figure 2

ground distance and thus can be associated with the skip. Figure 3 is an example of the type of echo that will result from this ground backscatter when displayed on an A-scope. The thirty millisecond sweep shown represents a range of about 4000 kms or 2500 miles. The transmitted pulse, of 2 milliseconds duration, occurs at zero time and the ground backscatter starts at a time range of 11 milliseconds. Figure 4 shows this backscatter as it might exist on several frequencies. Note how the backscatter delay increases as the frequency is raised. Note also the 2-hop backscatter shown on 16 megacycles.

These results were obtained on antennas oriented along a single azimuth. With a rotatable antenna, a PPI display (Figure 5) can be used to indicate the variation of skip distance on a given frequency as a function of azimuth. A-scope displays (with a sweep length twice that of the PPI display) of the ground backscatter for the four cardinal points of the compass are also shown in Figure 5. This backscatter display indicates poor communication or propagation conditions to the north, good single hop conditions to the west, and good multiple hop conditions to the south and east. A "short skip" propagation mode, probably supported by a patch of sporadic E ionization, is also indicated in the northwest.

All of these examples have shown the backscatter on a time base which is indicative of the slant range to the echo. In order to convert this into distance along the earth's surface, the height at which the apparent reflection occurs must be known. This conversion from slant range or backscatter delay time to skip distance is considered to be purely geometrical and can be made with the aid of a graph such as Figure 6. It is true that the propagation mode must be identified and the layer height estimated before delay time can be converted to the skip distance. However, a little experience on the part of the observer, together with some knowledge of the history of formation and movement of a particular group of backscatter, allows quite accurate mode identification. For example, the backscatter shown in Figure 3 was propagated via an F-layer mode. If a 300 km reflecting layer height is assumed, the skip distance is found to be 1500 km. A table giving best estimates of F-layer heights for various times and locations is adequate for this mode. One hundred kilometers can always be used as E-layer height. It should also be noted that the skip distance for a given delay time is not a very strong function of layer height, especially at the longer ranges. Thus, errors in estimating layer height are not very serious.

The backscatter records shown in Figures 3, 4 and 5 were obtained using equipment similar to Raytheon's AN/GPQ-3 Propagation Frequency Evaluation Set. This is a relatively low power pulse system

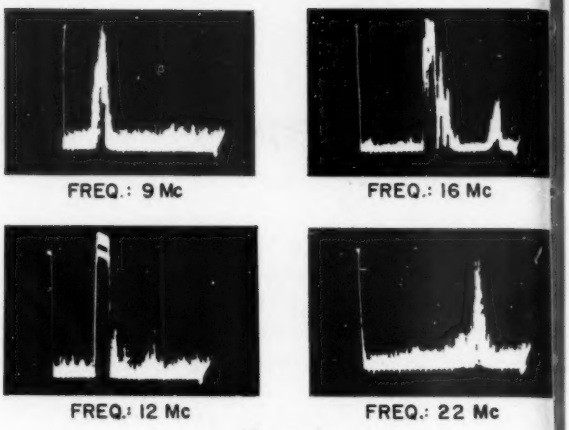


Figure 4

radiating 1 kilowatt of peak power in a pulse 2.5 milliseconds wide and occurring 20 times per second. The timing and display equipment is similar to that employed in radar, although the time base is considerably longer than that of most radars. This equipment has been used by the Strategic Air Command, US Army Signal Corps, the Air Research and Development Command, the Voice of America, Radio Free Europe and the Naval Research Lab.

Operational Use and New Techniques

The value of this type of propagation information to a broadcasting station or communication center is fairly obvious. Propagation conditions over a particular propagation path can be evaluated, the proper frequency for operation determined, relative signal strengths estimated, and possible changes in operating frequency anticipated. The use of the COZI system as it now exists in its pulse form has been awkward for most station operators, however. Special transmitters and antennas must be available for sounding, or traffic on the operating transmitters (possibly modified for pulse operation) must be interrupted for the backscatter sounding. It would be very advantageous if the skip distance information could be obtained without resorting to special pulse systems. The required transmission time could be obtained using other types of modulation if the transmitted signals could be stored for comparison or cross-correlation with the returning backscattered signal. The only requisite on the modulation would be that it have the bandwidth required to permit a delayed copy of the transmitted intelligence to be compared with the backscattered waveform to obtain transmission delay without ambiguity. Since pulse systems usually employ pulses about 1 millisecond long, continuous modulated transmissions with a correlation time of this order or a bandwidth of at least 1 kc should be adequate. Ordinary AM broadcasts as

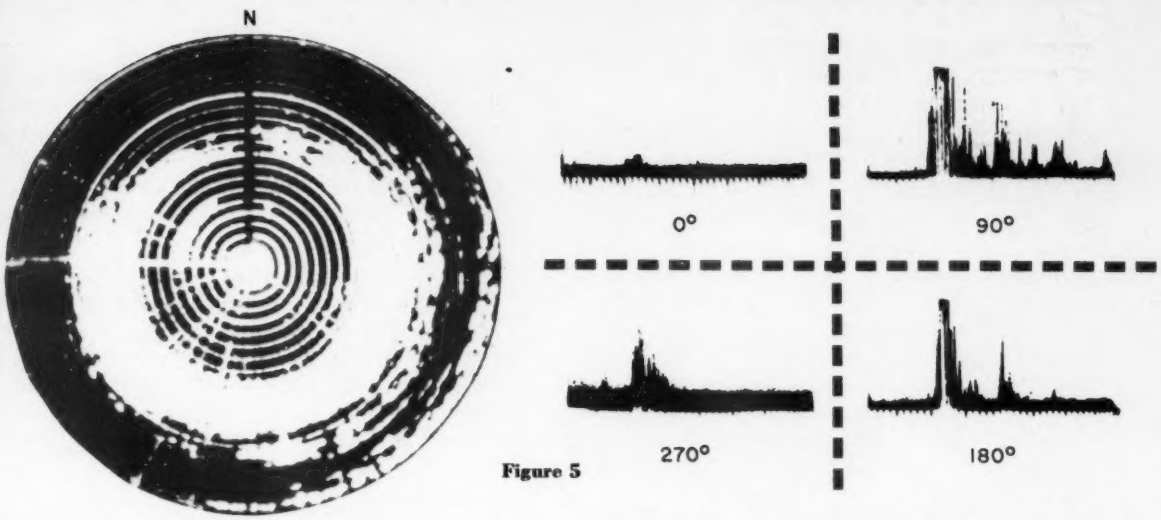


Figure 5

well as many ionospheric communication transmissions satisfy this condition.

To implement these ideas, methods of recovering backscatter information from arbitrary modulation systems were considered. A method of correlating the transmitted intelligence with the backscattered waveform was obviously necessary. The two major problems were the storage of the transmitted intelligence for comparison with the returning backscatter signal, and the separation of the transmitting and receiving facilities in order to avoid self-jamming. The problem of storing or delaying the referenced transmitted intelligence was solved by the use of digital recirculating delay lines.

Several experimental tests were performed at Raytheon's ionosphere sounding station at South Dartmouth, Massachusetts. It was found that signals transmitted from WRUL, an overseas broadcasting station located at Scituate, Massachusetts, could be received at South Dartmouth via the backscatter mode. Reference intelligence for comparison with the backscatter signal could be obtained over a telephone line. The referenced transmitted intelligence stored in the recirculating delay lines was compared with the

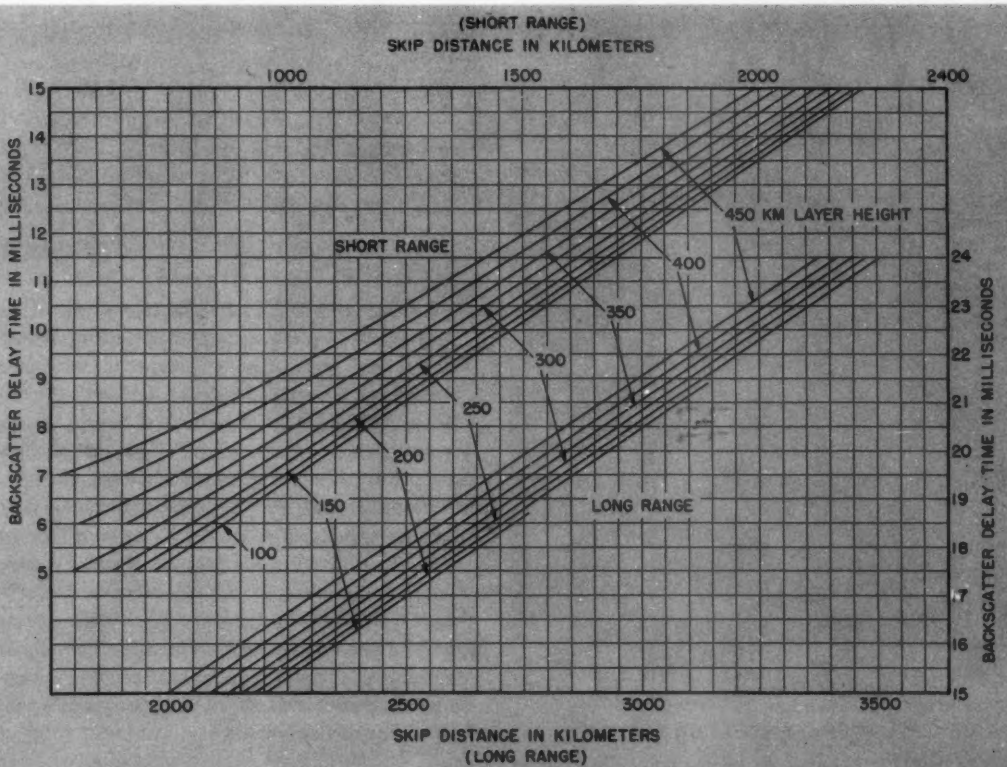


Figure 6

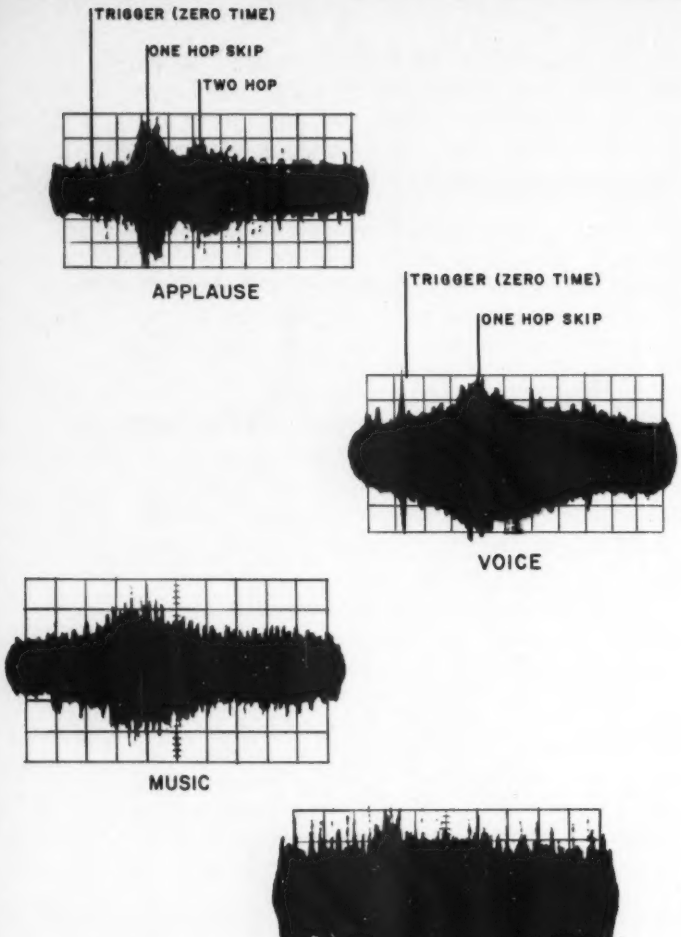
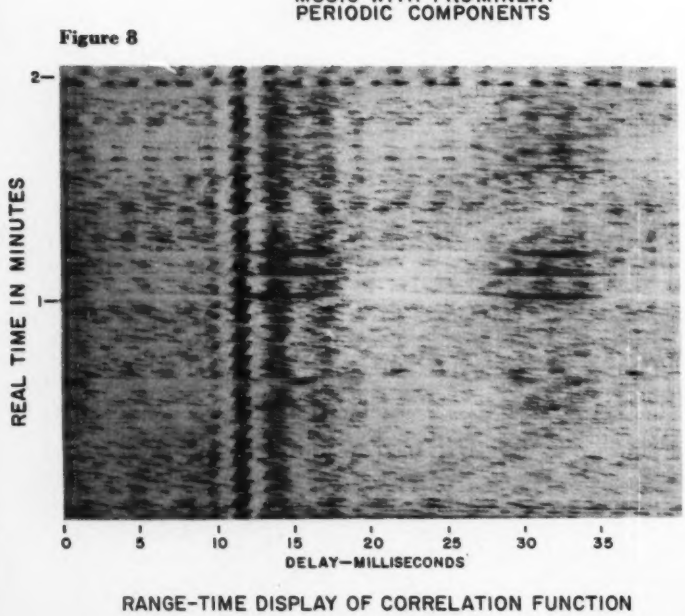


Figure 8



RANGE-TIME DISPLAY OF CORRELATION FUNCTION

received backscatter signal by a simple coincidence amplifier. The output of this coincidence or correlation amplifier presented the cross-correlation function as an A-scope display.

The results of one experiment are illustrated in Figure 7. Several examples are shown to illustrate the correlation functions obtained for various types of program material. The best results were obtained in the case of applause (a wide-band noise-type signal) and fairly good results in the case of voice. In the case of music the results were less consistent; where orchestral pieces containing many frequencies were used, the results were fairly good. However, when the music contained prominent periodic components, such as is the case with a single instrument or a pure-toned voice, ambiguities appear in the A-scope presentation corresponding to the multiple correlation points of the periodic components. The correlation function displays shown in Figure 7 were obtained photographically with an exposure time of approximately 20 seconds. To an observer watching the A-scope, the position of the peak in the correlation function is not as obvious as in these pictures. The integration provided by the long film exposure time brings the position of the correlation function into prominence.

To improve on the visual display and to provide a long time integration effect, the output of the correlator was displayed on a facsimile device to provide a range versus time presentation similar to that normally used in oblique incidence ionosphere sounding work. A sample of this type of display is shown in Figure 8. The range to the cross correlation function or backscatter is shown as a function of time for a period of 3 minutes. In this type of display the position of the correlation function is quite apparent. If this presentation were used in a communication center, the skip distance or zone of communication could be continuously and very conveniently monitored.

Conclusions

The backscatter, or COZI, technique for measuring skip distance and communication zones is an extremely useful tool for the long distance broadcaster or communicator who must rely on ionosphere propagation. Widespread use of the method would conserve spectrum space by eliminating the guesswork in frequency selection, thereby guaranteeing that each operator used only that part of the spectrum necessary to accomplish his immediate objective. The operational difficulties brought about by the use of a pulse system would be eliminated if a correlative type COZI were employed to take advantage of the normal modulation method used at the communication center. Use of the technique offers the advantages of savings in both operating cost and spectrum space while, at the same time, improving reliability.

Techniques for Ultra-High Temperature Systems

[redacted]

COMPLETE electronic circuits are currently being designed and tested for operation in ambient temperatures of 500°C. For certain of the components in these circuits, 500°C is in the ultra-high temperature range, which means they must be capable of operating literally in a red-hot condition. The present article will discuss some of the radical changes in the properties of materials which occur at such elevated temperatures, and will describe some of the techniques that have been applied in the design of successful ultra-high temperature systems. While the authors' interests lie principally in the field of magnetic components, the topics discussed will be pertinent to the many other types of units which go to make up a complex piece of electronic gear.

In a previous article [November-December 1957 issue of ELECTRONIC PROGRESS] the authors described the use of newly available fluorochemical insulating materials, coupled with effective cooling design, as a means of upgrading the capability of electronic equipments to withstand severe thermal environments. In this article, we propose to discuss a diametrically opposite approach, whereby through the initial selection of suitable temperature-resistant materials and the application of special techniques in production, equipment can be designed to withstand severe extremes of temperature without any means of cooling other than radiation.

Functionally, the basic parts out of which the various components are constructed are: (1) Insulating members; (2) Conducting members; (3) Magnetic members; (4) Structural members.

Traditionally, the upper limit of operating temperature has been determined by the thermal endurance of the insulation in the system. A large number of insulating materials are organic in nature, and therefore vulnerable to the effects of oxidation and pyrolysis. The life of organic insulating materials varies logarithmically with the reciprocal absolute temperature, and is expressed by the Arrhenius equation:

$$L = A(e^{b/T} - 1)$$

where L is life in hours, T is absolute temperature, A and b are empirical constants. As a result of this relationship, the life of insulation may be expected to diminish by 50 per cent for roughly 10°C increase in temperature. This relationship is illustrated in Figure 1. Class A insulators are organic materials used up to 105°C (e.g., paper). Class B insulators are organic materials used up to 130°C (e.g., epoxies). Class H insulators are organic plus inorganic materials normally used up to 200°C. Note that the life of even the most stable organic types, silicone and teflon, is reduced to a matter of a few hundred hours at 300°C.

In entering the realm of ultra-high temperature, it therefore becomes necessary to find substitutes for the

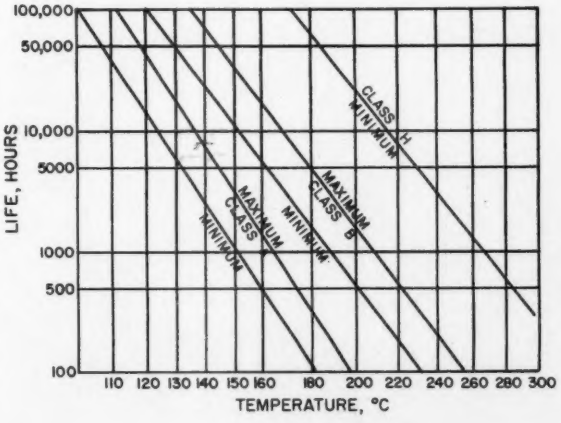


Figure 1

organic materials. In so doing, the first handicap encountered is the inherent non-flexibility of inorganic and ceramic insulations. The winding of inductive components requires flexible, abrasion-resistant insulation for conductors, and flexible sheet insulation between the layers of a coil.

Fortunately, there is a way in which a degree of flexibility can be imparted to inorganic materials. This is by spinning or plating material in thin fibers. Nature, over the course of the ages, has produced bundles of silicate fibers as chrysotile asbestos, and "books" of laminar sheets as muscovite and phlogopite micas. Man has learned to spin fibers out of siliceous materials such as glass, quartz, and aluminum silicate. He has improved upon the natural micas, replacing the water present in natural mica with fluorine to produce synthetic fluorphlogopite, stable to 1000°C (Figure 2). Further, he has circumvented the increasingly acute shortage of large mica splittings by finding a way to delaminate mica scrap and recombine the platelets into sheets of material which may be several feet in width and as little as a thousandth of an inch thick. This feat has been accomplished by utilizing the residual electrostatic forces of attraction present in freshly delaminated mica. As a result, we have available flexible fibers, papers, and woven fabrics of inorganic origin, exhibiting good dielectric qualities and capable of withstanding extremely high temperatures.

A new type of flexible inorganic layer insulation has been developed in our own laboratory. This material has as its basis the bentonite clay films studied by Dr. Ernest Hauser of M.I.T. during the 30's. We have improved tensile and tear strength by incorporating in these remarkable clay films a quantity of inorganic fiber, such as glass, quartz, aluminum silicate, or potassium titanate. Strength can be further improved by applying a thin coating of silicone resin; or if desired, a thin layer of polyvinyl alcohol may be added for temporary handling strength, and subsequently burned off after the coil is wound. Films as thin as five ten-thousandths of an inch have been prepared in this manner, with breakdown voltages of 1500 volts per mil.

The electrical characteristics of all insulating materials suffer severe deterioration at ultra-high temperatures. As plotted in Figure 3, typical resistance values in the range of 1,000,000 megohms at room temperature drop to 100 megohms at 600°C. This is due to the fact that conductance in good insulators is in large measure ionic, and the mobility of ions increases with temperature. The presence of alkali metal ions in glass is a contributing factor to its relatively poor insulating properties at high temperature. Reduction in alkali content results generally in high softening point; electrical grade glass is a compromise between low melting point and good electrical quality. Alkali-free materials, such as aluminum oxide, zirconium oxide, boron nitride, and others are highly refractory and difficult to manipulate, but show superior electrical characteristics at high temperature. Such materials are outstandingly useful where a mas-

Figure 2

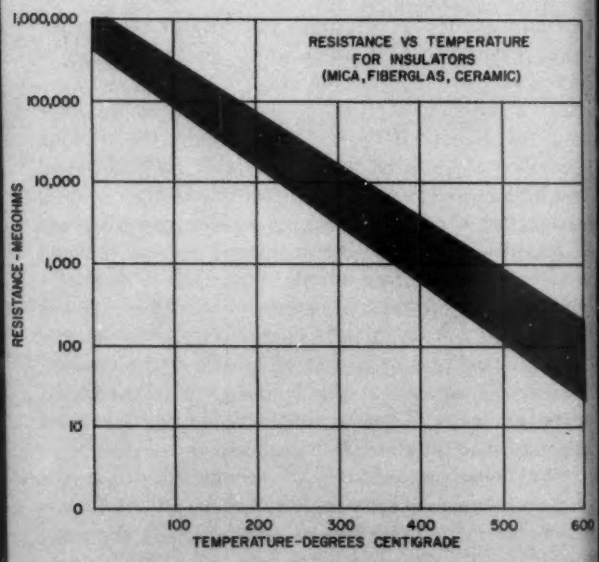


Figure 3

sive piece of insulation is required, as for example in terminal bushings.

Providing a good insulating environment at high temperature is a particularly troublesome problem for many reasons. For one thing, few materials exist which remain in the liquid phase at these temperatures. Even if a suitable liquid could be found, thermal expansion and contraction would present insurmountable obstacles to its use. Therefore, the preferred method of packaging encloses all components in hermetically sealed cases filled with inert gas. High dielectric strength and thermal stability are the requirements on which selection of a suitable gas is based. Dielectric strengths of the more stable gases are plotted against pressure in Figure 4. Unfortunately, the gases of highest dielectric strength have insufficient thermal stability for ultra-high temperature use. Perfluorethane is sufficiently stable for units operating at temperatures only up to 350°C. For higher temperatures, it is necessary to use nitrogen at a density sufficient to provide the required electrical breakdown strength. This means two to three atmospheres pressure at room temperature, 6 to 9 atmospheres at 600°C. Containment of such pressures in a case of minimum weight presents no mean problem to the mechanical engineer. All units must be leak-tested on the helium mass-spectrometer leak detector to insure a perfect hermetic seal.

Certain insulating materials perform dual functions as insulators and structural members. Adhesives and potting compounds are good examples of such materials. The problem posed by adhesives which are not

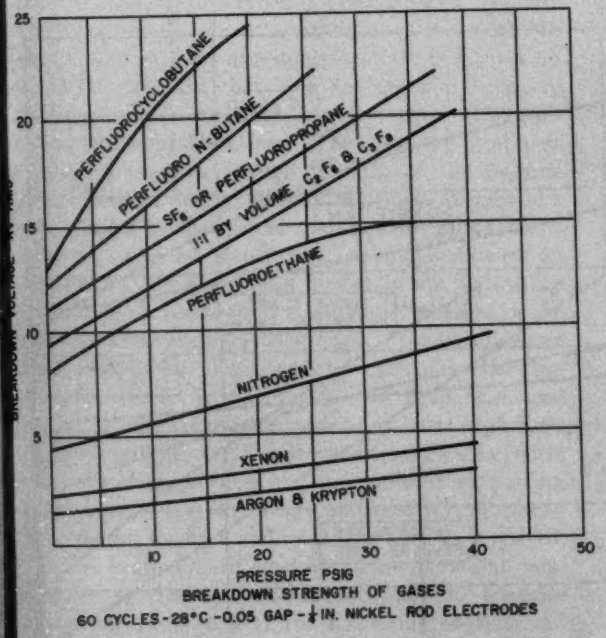


Figure 4

those of the conductor metal itself. The best conductor metals, copper and silver, show a marked increase in resistivity with increasing temperature. Referring to Figure 5, it can be seen that the resistance of these metals at 600°C is over three times the resistance at room temperature. I^2R loss and IR drop in inductive components are increased proportionately.

The problem of insulation for high-temperature conductors still awaits a completely satisfactory solution. Available commercial conductors include fiberglas-served copper and silver, anodized aluminum, and ceramic-coated nickel-clad copper wires. Glass fiber-served wires exhibit excellent resistance to temperatures up to 600°C, but have poor space factors due to the relatively large bulk of the fiberglas coating. The problem becomes more acute in the fine wire sizes; for example, a #40 wire wound into coil form consists of only 17 per cent copper by volume. Anodized aluminum also has disadvantages. Its melting point is 650°C and its conductivity is only 61 per cent that of copper. Nickel-clad copper wires initially have 65 per cent of the conductivity of pure copper, but upon prolonged heating show an increase in resistivity due to diffusion of nickel into copper with formation of an alloy of high resistance.

Figure 6 summarizes the state of the art of high temperature conductors. The curves show relative conductance [per cent conductivity relative to copper (volume metal/total wire volume)] for a number of commercial and developmental wires. The "double film" curve refers to a conventional double-organic-

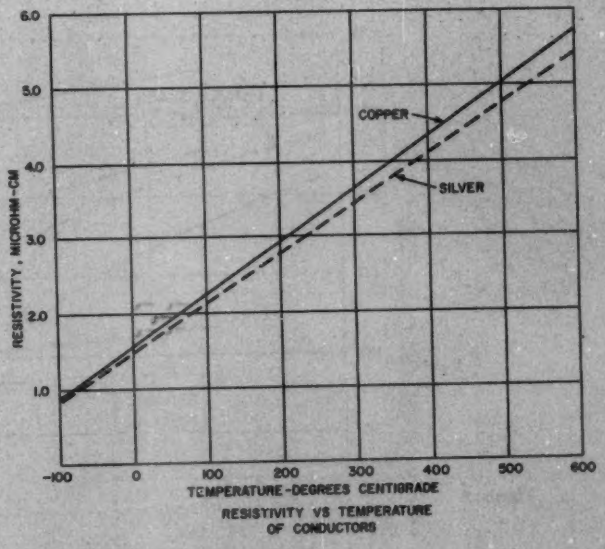


Figure 5

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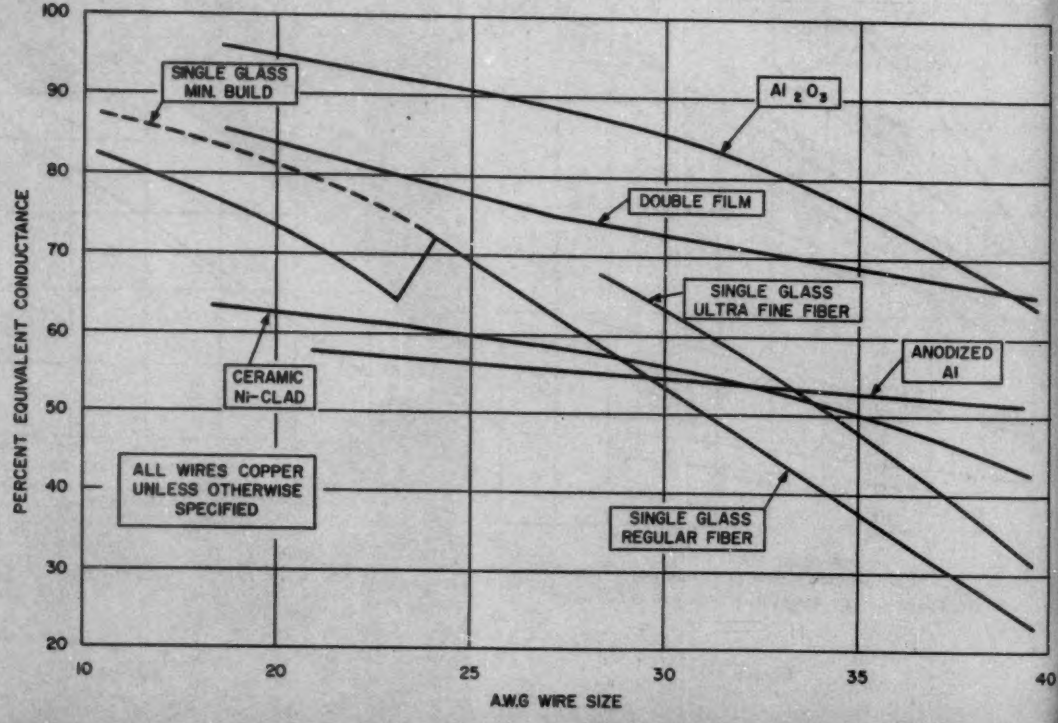

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Certain insulating materials perform dual functions as insulators and structural members. Adhesives and potting compounds are good examples of such materials. The problem posed by adhesives which are not resistant to high temperature has been eased by the discovery that certain types of silicone resins, unstable when exposed to air at temperatures above 250°C, can be used in inert atmospheres at temperatures up to 600°C, provided that they are given a degassing treatment under vacuum at a high temperature following the usual 200°C cure. The degassing treatment removes a portion, though not all, of the organic groups present in the silicone polymer. Weight loss when heated in vacuum at temperatures up to 600°C is on the order of 25 per cent, as compared with 50 per cent for the same resin heated in air, indicating that a large proportion of carbon still remains in the molecule after vacuum treatment. Properly selected resins retain a large measure of their bonding strength, exhibit excellent electrical properties, and can be operated for long periods at very high temperatures without further degradation. By admixture with refractory powders and inorganic fibers, potting compounds of zero shrinkage and controllable porosity, resistant to shock and vibration, may be prepared.

In the evaluation of conductors for ultra-high temperature service, it becomes necessary to consider jointly the properties of the insulating coating and those of the conductor metal itself. The best conductor metals, copper and silver, show a marked increase in resistivity with increasing temperature. Referring to Figure 5, it can be seen that the resistance of these metals at 600°C is over three times the resistance at room temperature. I^2R loss and IR drop in inductive components are increased proportionately.

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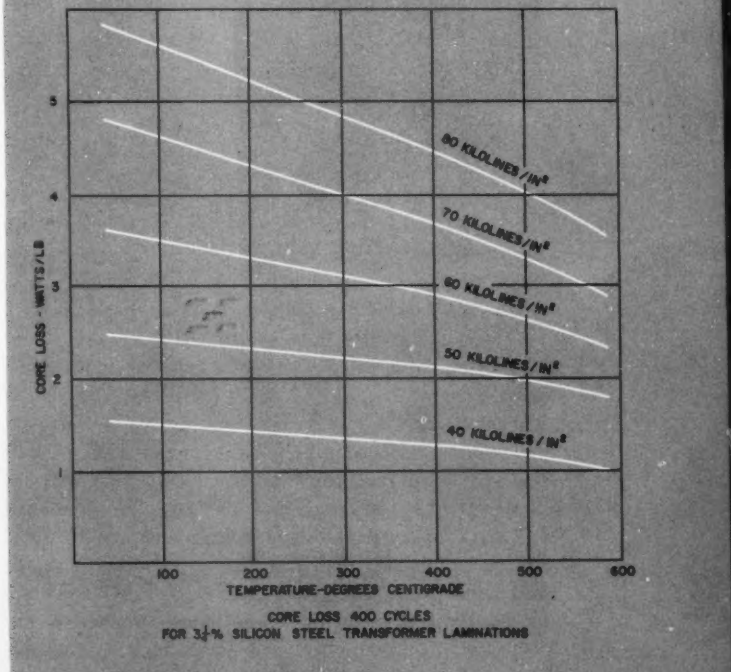


Figure 7

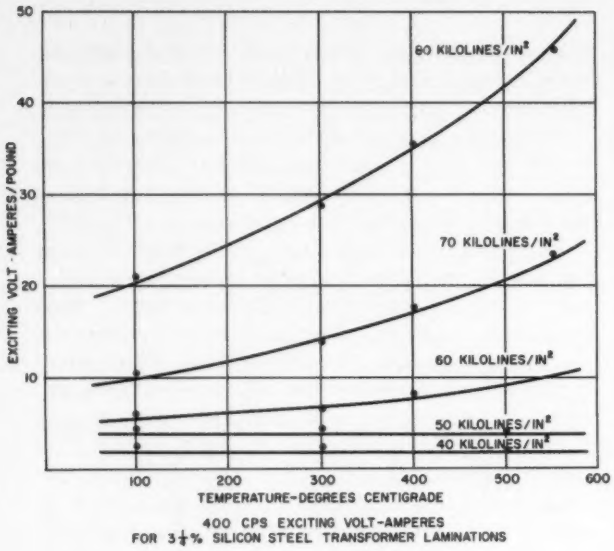


Figure 8

Figure 9

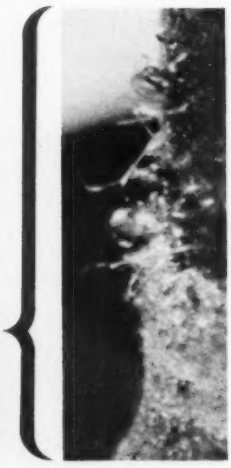


Figure 10

film coated wire, such as heavy formvar or heavy teflon. The poor relative conductance of commercial high temperature wires, particularly in fine wire sizes from #26 to #40, is clearly evident from the curves.

A great deal of development work on high temperature insulated conductors is currently going on in our laboratories and elsewhere. An aluminum-oxide coated wire, represented at the top of Figure 6, has been developed by Raytheon's Receiving Tube Division, following a method which had proved successful in the coating of tungsten filament wires. This wire has an excellent space factor and may provide the answer to a wire for service in inert atmospheres up to 400°C. We have investigated anodizable metallic coatings, and have produced a tantalum clad wire which can be anodized to yield an exceptionally tenacious and flexible oxide film. Following another approach, we have electrophoretically coated silver and copper wires with inorganic fibers, specifically quartz, aluminum silicate, and potassium titanate fibers. We have also studied the formation of insulating coatings by chemical means. Examples of such coatings are electrolytically formed phosphate and chromic oxide coatings on silver, and fluoride coatings produced on copper and aluminum by heating in fluorocarbon gas. From still another angle, we have conducted an investigation of the diffusion of metallic coatings. As a result of this work, we now have a metallic coating metal for copper and silver which is free from the diffusion effects that cause other clad wires to increase resistance upon aging. Any one of these various methods of attack may provide the low space-factor wire which is essential in the development of miniaturized ultra-high temperature components.

Turning now to the category of magnetic materials required in transformers and reactors, radical changes are found to occur in these materials at extremely elevated temperatures. As shown in Figure 7, core losses at high flux densities are reduced by roughly 40 per cent at 500°C. Core losses are of two types: hysteresis losses which may be considered due to molecular friction accompanying the orientation of iron atoms with the rapidly changing magnetic field; and eddy current losses caused by induced currents in the magnetic core. Losses of the latter type are customarily minimized by "core plating" the laminations with a suitable insulating material, such as magnesium oxide or phosphate. Interlaminar resistance deteriorates severely at very high temperatures. Over a long period of time, diffusion of the insulating layer into the iron takes place, causing a large permanent loss in resistance. A simple solution to this problem has been found in the use of extra heavy layers of inorganic insulating coating, up to 2 mils in thickness.

Exciting current of magnetic cores increases with temperature, as shown in Figure 8. This effect, which is especially marked at the higher flux densities, is due to the lower permeability of silicon steel as the Curie point of 750°C is approached. As a result, in the design of magnetic components for ultra-high temperature operation, it becomes necessary to limit the maximum flux density to values 10 to 15 per cent lower than those used in conventional units.

Included in the category of "structural members" are such things as containers, mounting brackets, and hardware in general. Commonly used metals such as cold rolled steel are found to have insufficient strength for many purposes above 500°C. It therefore is necessary to use high hot-strength stainless steels for cases and mounting hardware.

Assembly of the various parts brings into play

many facets of the brazing art. Fine wires are brazed to leads using "tweezer" brazing tools especially designed for delicate work. A similar technique is used for joining lead wires to terminals. Covers are torch brazed to cases for 350°C service; heliarc welding is employed for 600°C units. Specially designed metallized ceramic terminals employ low-carbon nickel parts for maximum resistance to oxidation in air. The titanium hydride metallizing process for ceramics is the only method found to date that gives acceptable results at the 600°C level. Terminals are induction or furnace brazed to headers in dry hydrogen.

Caution must be exercised in the use of silver-containing brazing alloys in contact with ceramic insulating members at high temperatures. Under certain conditions, migration of silver along ceramic surfaces has been found to lead to the formation of conducting films and the growth of metallic whiskers on the surface of the ceramic. This effect is clearly visible in Figure 9 in which the dark areas that can be seen on the ceramic are silver. Silver whiskers are visible growing along the base of the ceramic at the left. A more enlarged view of the whiskers is given in Figure 10. This situation may be corrected by the use of nickel-gold brazing alloy instead of silver.

An article on ultra-high temperature electronics would be incomplete without some reference to heat transfer at elevated temperature. Since the quantity of heat radiated per unit surface varies as the fourth power of the absolute temperature, it is found that at 500°C and upwards radiation becomes the dominant mode of heat transfer for the geometries used in these components.

Figure 11 is a plot of radiation coefficient (heat transferred per unit area per degree) versus thermal flux (heat input) for various ambients up to 500°C. Clearly, at 500°C ambient there is at least seven times as much heat transferred due to radiation than at 100°C. For a given heat input, the radiation will be more effective in keeping the temperature from increasing if the ambient is high. Temperature gradients inside and outside the equipment container are minimized by coating all surfaces with a high-emissivity finish. Natural metal-oxide finishes provide some improvement in radiation, but a more effective method, applicable to stainless steel and nickel, is to immerse the metal in molten sodium dichromate at 400°C. This treatment yields a thermally and optically "black" surface coating which is resistant to corrosion at high temperatures.

The external appearance of a group of ultra-high temperature transformers built by Raytheon for the Navy is illustrated in Figure 12. Voltage ratings of these units are as high as 5400 rms and 16 kv pulse. Teamed up with ceramic vacuum tubes, capacitors, resistors and semiconductors under continuing development by various companies throughout the country, these units are expected to make an important contribution to the new art of ultra-high temperature electronics.

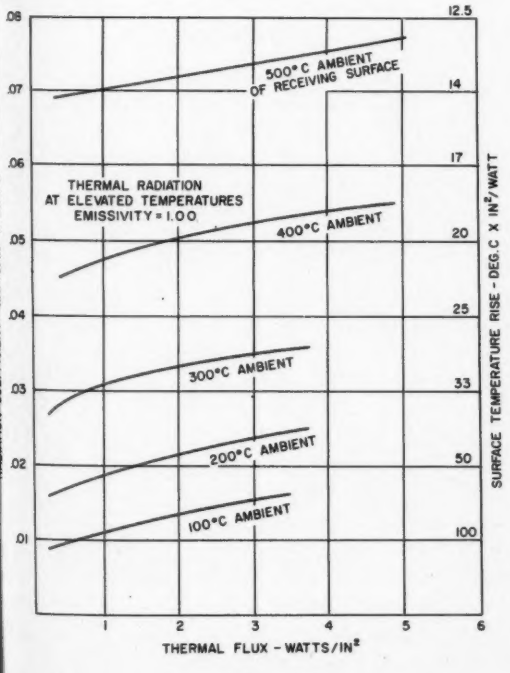


Figure 11

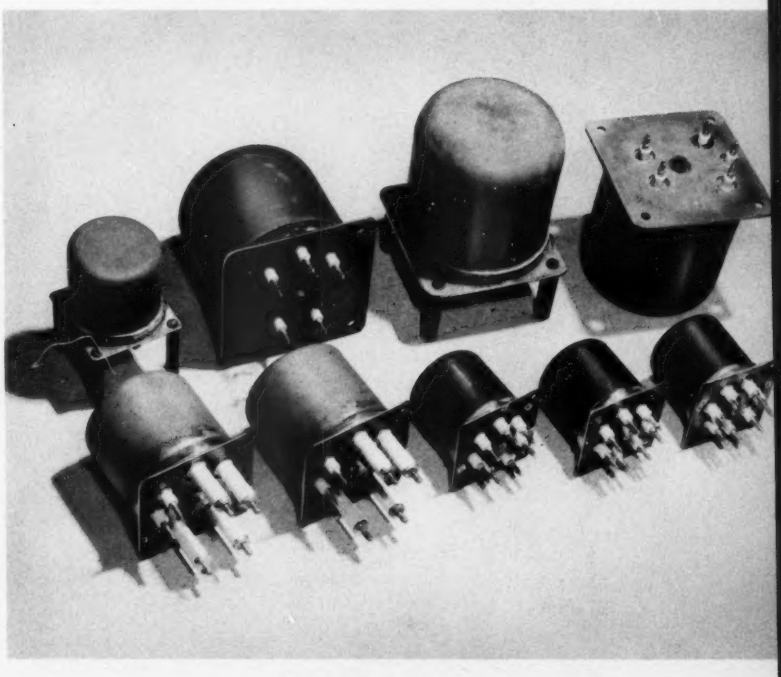
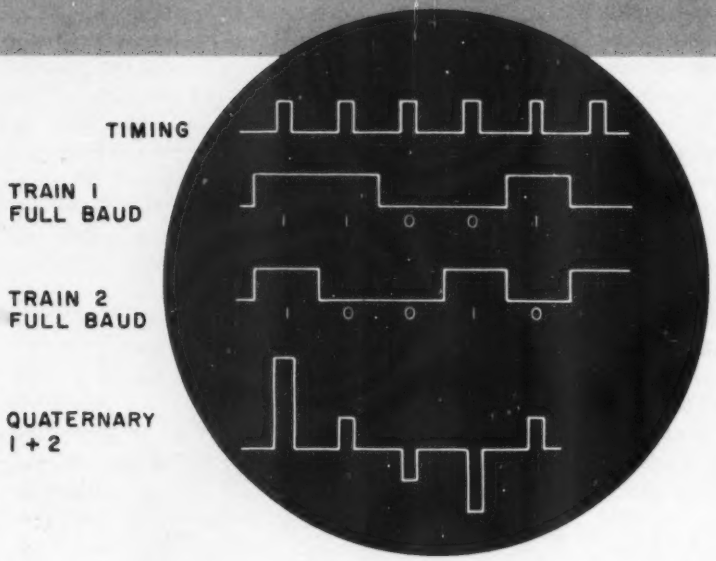


Figure 12

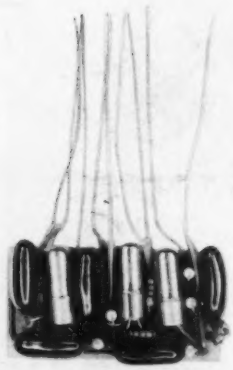
PULSE CODE MODULATION



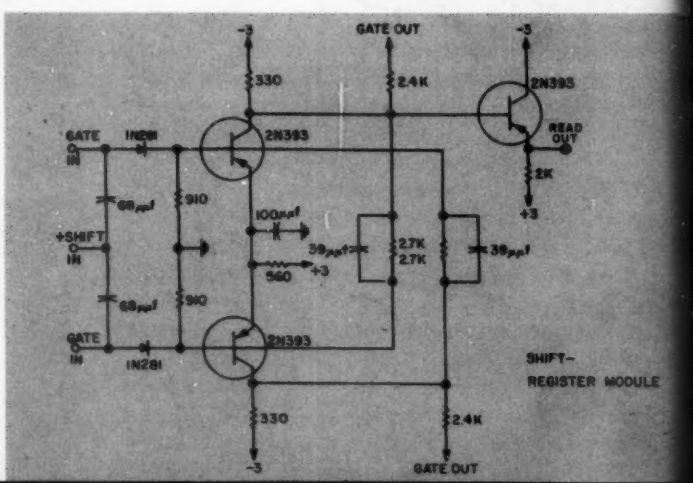
THE QUATERNARY WAVE combines information from trains 1 and 2, and the timing pulse regulates the width and position of the quaternary output wave. Thus, twice as much information is passed through the same bandwidth as is required for one train.

PCM is a new method of coding voice and analog information into digital form. It provides a completely digitalized message by time-division multiplexing of voice circuits. Adaptation of the technique offers advantages in signal-to-noise characteristics, signal regeneration, message security and equipment reliability not usually achieved with conventional techniques.

A 96-voice channel, fully transistorized PCM equipment for cable and radio transmission meeting rugged military requirements has been developed by the Communications and Data Processing Operation of Raytheon's Equipment Division. In this system a sampling frequency of 8,000 cycles is used. Each sample is coded in six-bit binary form, at a bit frequency of 4.6 mc. Many new circuit techniques closely allied to high-speed data processing and computer systems are being developed for this equipment.



TYPICAL MOLDED MODULE used in Raytheon PCM equipment comprises logic circuitry required for a 2.3 mc shift register shown in the diagram. Other modules are used for repetitive and-or gates, flip-flops and binary-storage elements.



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